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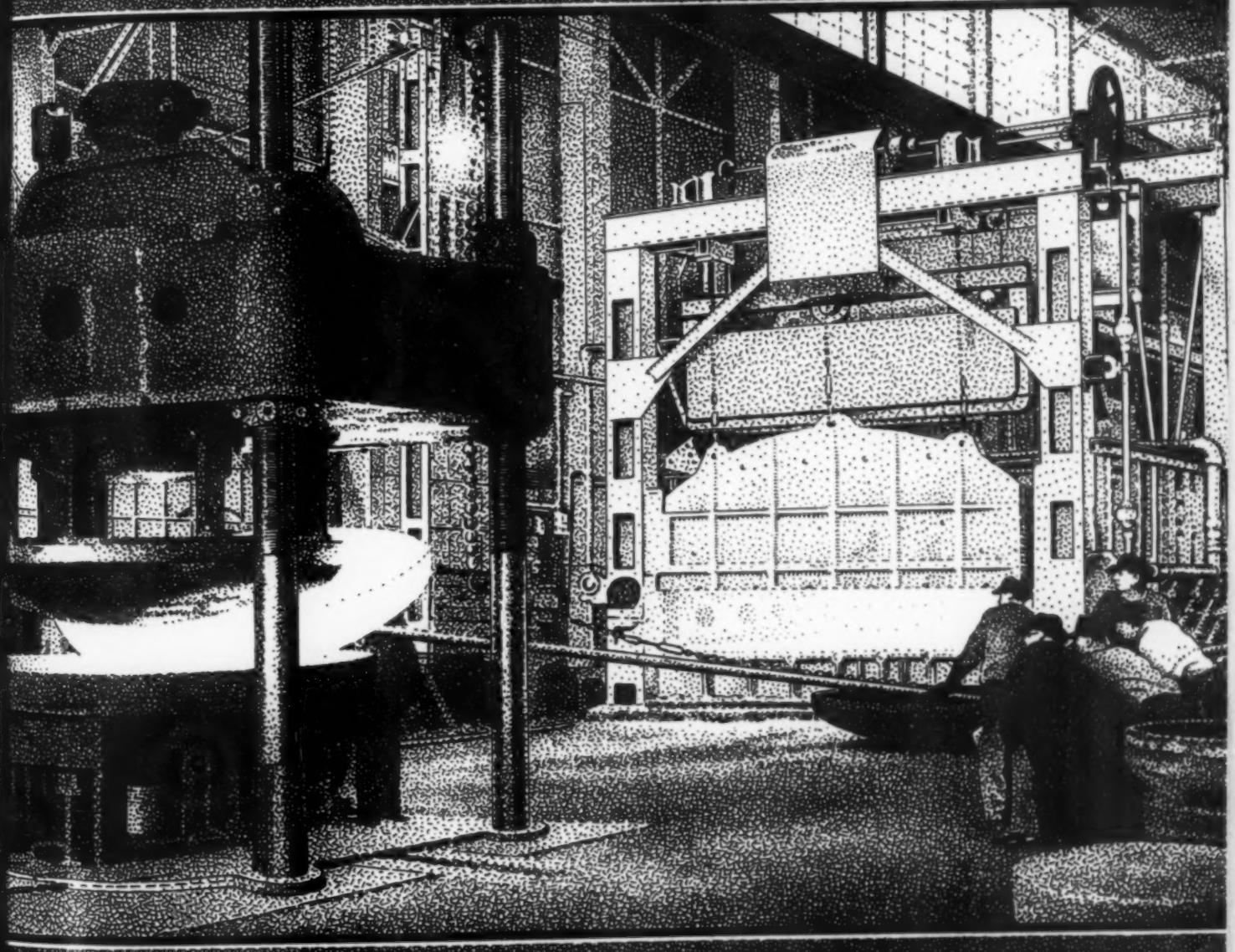

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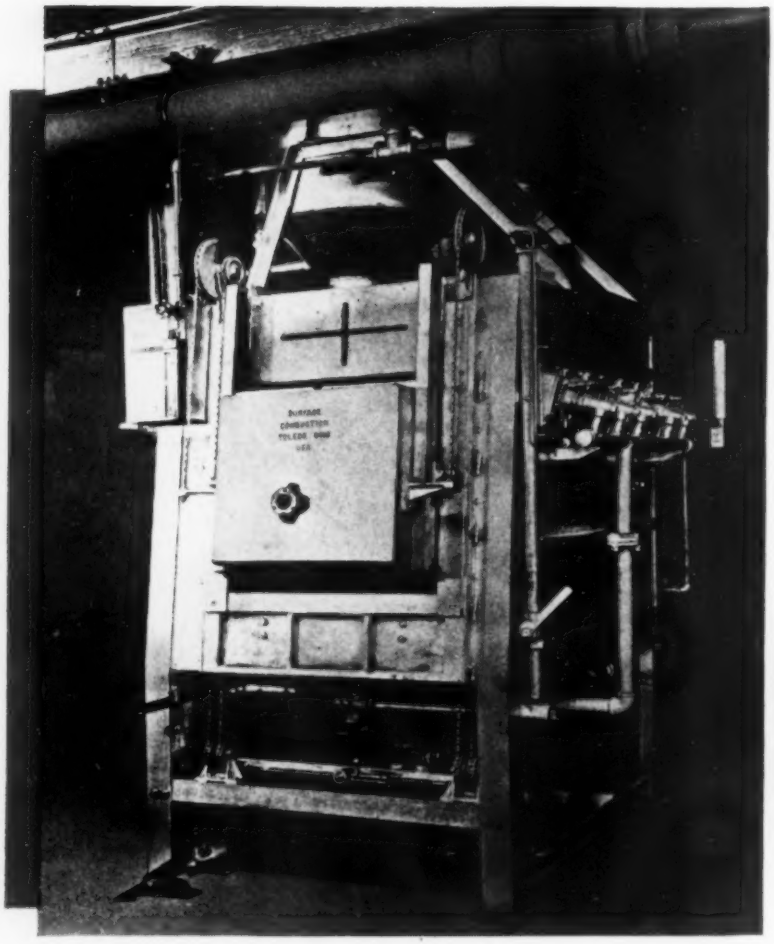

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July 1947,

Vol. 52, No. 1

Cover picture of a flanging press at the Warren plant of the Struthers Wells Co. is by Carl Sorensen.

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Critical Points

(Mainly About Metallurgical Oxygen)

By the Editor

LIKE "old home week" to gather with technical editors at the Linde Air Products Co.'s research laboratory in Tonawanda, near Buffalo, and to find there so many friends in the Linde organization who date back a quarter of a century when the editor was also a "Linde man". The occasion was a symposium on the use of oxygen in steelmaking. John Gaines, assistant superintendent of the laboratory, summarized the findings on nearly a thousand openhearth heats. Later, vice-president Lyman Bliss, in charge of oxygen plants, discussed the problems of producing and transporting the large quantities involved. We inspected the laboratory, viewed demonstrations of special burners, and next day visited the enormous plant at East Chicago where 400,000 cu.ft. of 99.5% oxygen is produced every hour, and shipped as liquid in trucks and tank cars — 400 tons per day. For the past eight months an experimental section there has been separating 200 tons of oxygen per day (and the product blown off), to develop techniques and determine costs on oxygen of varying purity and at varying pressures and demand factors. . . . . In an interval of about 25 years, the whole oxygen business has gone to a different plane of reference, as it were. Some 40 producing plants then were located in strategic positions; the average made 1000 cu.ft. per hr. Now the most of Linde's production comes from four plants like the one at East Chicago, each one of 200 times the capacity of the old ones. *Then* the gas was delivered exclusively in steel cylinders, each containing 220 cu.ft. compressed to 2000 psi.; *now* there are several times as many such cylinders in use, but by far the largest quantity of oxygen reaches the user as a liquid, is so stored, and vaporized and piped away on demand. Then, a favorable price in largest quantities was 1¢ per cu.ft. delivered; now it would be 0.25¢ ($60 per ton). Then, as now, a large fraction of the selling price paid for delivery; disregarding delivery costs Bliss ventured to say that production of metallurgical oxygen from a very large, well designed plant operating at constant demand, delivering gas at low pressure for continuous use so expensive storage systems are eliminated, might cost as low as $6 to $8 per ton of contained oxygen, depending principally on power and water costs. Anticipated costs in the enormous plant (2,000,000 cu.ft. oxygen per *hour*) now being erected in Brownsville, Texas, for the manufacture of gasoline from natural gas, will be $2 per ton — estimates made by P. C. Keith, president, Hydrocarbon Research, who designed the process, and D. W. Wilson of Arthur G. McKee & Co., who is engineering and building the plant.

Revolution in the oxygen business

THUS the idea recurring now and then in metallurgical literature for the last 30 years that oxygen or enriched air might be had cheaply has, at last, some basis in fact. Perhaps it sprung up periodically when someone rediscovered the theoretical power requirements; from thermodynamical considerations, all that is really necessary is the power required to compress five volumes of oxygen into one, and five volumes of nitrogen into four. Any practical operation, however, runs into the fact that some heat radiates through the best insulation, that heat transfer from hot to cold gas is never complete, that it takes power to transport gas from one place to another, and that extraction of liquid oxygen (or nitrogen) removes large quantities of refrigeration from the cycle. Advances in oxygen producing plants and details of the cycle have centered on minimizing these losses. The essential cycle remains the same: Compress air to an economical degree, liquefy most of the oxygen by refrigeration followed by expansion either through an orifice or a work engine, separate nitrogen from the liquid in a

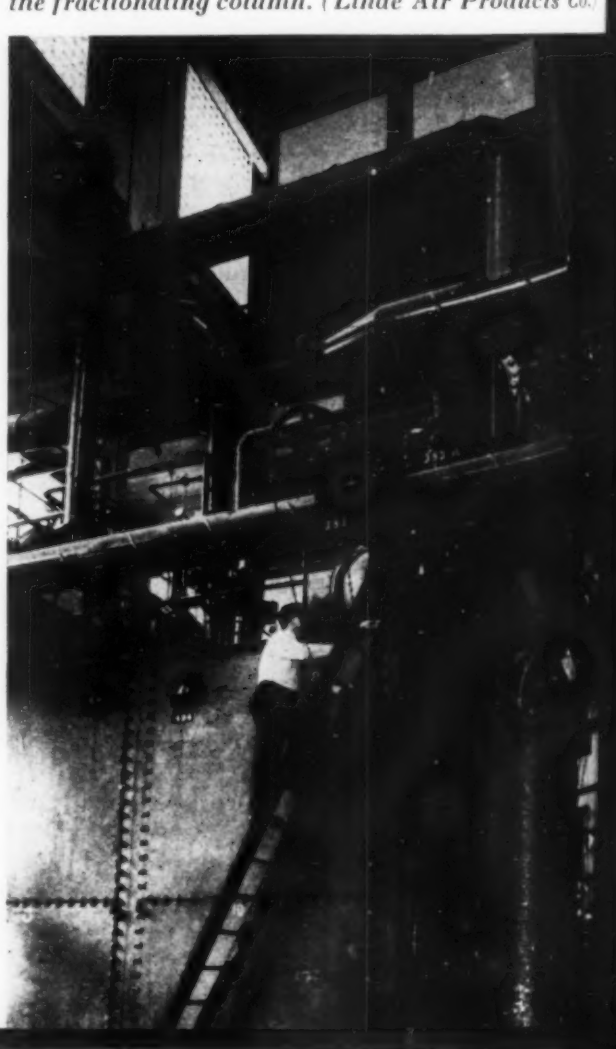
Economical production in large plants

fractionating column (oxygen's critical pressure and temperature is 730 psi. and −182° F., nitrogen's is 492 psi. and −233° F.), and transfer the refrigeration in the cold gases to the warm incoming air. Somewhere in this process, water vapor, CO_2, hydrocarbons and dirt must be removed. Much governmental sponsored research was done during the war on cycles, heat exchangers, compressors and expansion engines, with the result that many small, low-pressure oxygen plants of good efficiency were built for the mobile shops of army and navy during the war, and these will doubtless be attractive to many users of a medium quantity of oxygen, but it is reasonable to suppose that efficiency in all phases of the cycle will increase with size of plant. . . . . Two periodic sources of sensational news are the propaganda-wise Germans and the incredible Russians — "news" of oxygen so cheap that it will blow blast furnaces. What the facts are about Russia is anybody's guess. The truth about Germany seems to be that in the 1930's, when Hitler was actively preparing for war, instructions went out to increase production of fertilizer for food, petroleum from oil, and steel and cement from low-grade home ores. German nitrogenous fertilizer depends on cyanamide, and it requires pure nitrogen in its synthesis. Liquid air plants producing pure nitrogen made impure oxygen as a byproduct. It was "sold" to the steel industry at a nominal price; in the blast furnace it increased production, but unfortunately the high focus temperature put some calcium carbide into the slag and ruined it for cement. It was during these prewar years in Germany that Mathias Frankl suggested the use of regenerators on a short reversing cycle to transfer the refrigeration, rather than continuous counterflow heat exchangers like steam condensers, and devised a low-pressure cycle that produced 98% oxygen for about one-third the power consumption of the earlier high-pressure cycles. About 75 such plants were built in the late 1930's in central Europe and Russia, the largest with capacity of 125,000 cu.ft. of oxygen per hr. Power and labor consumption are thought to be of about the same order as that anticipated in the new large plant in Texas.

THIS matter of oxygen in blast furnaces is of perennial interest to the Editor since the day in college when his professor of metallurgy set a problem in thermal balance before the class, wherein Sir Lowthian Bell's classical analysis of the furnace's action was to be reconsidered on the supposition that the blast contained 25% oxygen. The variation in answers was so great, and the possible unknown influences so speculative, that the answer then was: "Iron of a sort increased; coke reduced; economics doubtful." Twenty years later (in 1926, as a member of the Linde Air Products Co.'s "Process Advancement Committee") he made a much more careful analysis and had considerable discussion with operators, but it led to the same general conclusion of his student days — nevertheless, he recommended that even with cylinder oxygen at $250 a ton it might be well to have it as a standby, piped to each tuyere, ready to boost the temperature locally as needed. Such a scheme should permit the coke on the charge to be reduced — some 10% excess was always carried to avoid those irregularities that might develop into trouble, and a little oxygen, now and then, might save several pounds of coke per ton, continuously. It seemed a good idea, too, to the operators of the Donner furnaces in Buffalo, but the experiment was killed by some of the top brass for political rather than technical reasons. Now, at long last, a real try is to be made of enriched air as a steady diet for a life-sized furnace, an

Blast furnaces on enriched air blast

Unit Taking Compressed Air at 80 Psi. and Delivering 200 Tons per Day of 90% Oxygen. Operator is climbing to top of regenerative heat interchanger; taller square structure alongside is the fractionating column. (Linde Air Products Co.)



experiment jointly sponsored by Bethlehem Steel Co., Air Reduction Co., and Koppers Co. Probably most of the other steel companies will reserve judgment (and action) until Bethlehem shows enthusiasm or pessimism. Bill Haven, who knows about as much about blast furnaces as any other articulate American, computes — on the basis of German operating data — that a modern basic furnace over here would make iron about $1.00 per ton cheaper with blast enriched to 25% oxygen. Since this hypothetical furnace would use one fifth of a ton of extra oxygen per ton of iron, the oxygen could not cost more than $5 a ton.

BUT WITH SURPLUS oxygen-producing capacity available from the gas companies, on the one hand, and a consumers' demand for more and more steel on the other, steelmakers have not hesitated to try oxygen to speed-up openhearth operations. First trials were made in the Hamilton plant of Steel Co. of Canada in 1942. By 1946 everyone was following suit. The easiest way was to tap existing oxygen pipe-line systems leading from storage (systems now installed in all steel mills) and inject some oxygen into the air at the oil or tar burners. Economics in this use of oxygen during meltdown may be appraised by data from 728 heats in 13 campaigns in nine openhearth shops, assembled by the Linde Co. Average time from tap to tap without oxygen was 13¼ hr.: with oxygen, it was 11.6 hr., a speedup of 1.65 hr. per heat or 12.4%. (All figures are weighted averages.) The average heat made 195 tons of ingots; 112 tons of cold metal was on the charge. Oxygen was used in each meltdown for 3¾ hr. at the rate of 38,000 cu.ft. per hr. Put in an oversimplified way, 1 hr. of furnace time was saved at the expense of about 3½ tons of oxygen. If an hour's furnace time, over and above the fuel, costs $80, *and all other conditions remained the same*, you could afford to pay $23 a ton for oxygen and still come out even. . . . . A considerably more effective way of using oxygen, after the scrap has been heated to 2500° F. or so, is to blow a strong jet of oxygen directly against the still solid metal; the hot iron burns, generating great heat, the surface layers melt and the superheated liquid (saturated with oxide) flows down through the incandescent mass below, giving up its heat where it will do the most good. Viewed through dark glasses, it looks like a mountain stream cascading down through broken boulders. While this may seem an extravagant way to put ore into a furnace, the heat generated during the oxidation of the iron remains almost completely in the bath (instead of three quarters escaping through the ports). Special, water-cooled high-velocity jet nozzles to be thrust through a door wicket have been designed. At the present time this appears to be not only the simplest but the most attractive application of oxygen during the melting stage in small openhearth or electric furnaces. In large steel mills where "tonnage, tonnage, more tonnage" is the order, the routine would probably be to use oxygen in end burners until the cold metal is quite hot, then switch the oxygen to one or two jet nozzles, which play on protruding chunks for 15 or 20 min., then back to the end burners to boost the flame temperature until the roof gets so hot it is about to drip.

Speeding the meltdown in an openhearth

THIS arm-chair metallurgist, who remembers his youthful astonishment at the completeness, dispatch and brilliance with which the bessemer converter blows the carbon out of several tons of molten pig iron, has often wondered why a similar scheme has not been used long since in the openhearth, where most of the conditions seem ideal for slow motion. Maybe if it were not for the necessity of driving carbon clear down in many of the stainless steel analyses (despite the recarburizing influence of the incandescent carbon electrodes) oxygen — or air — would never have been injected into the electric or openhearth steel bath. Once tried it works so expeditiously, especially on the last few points of carbon, that oxygen seems a "natural" for the low-carbon rimming steels. For example, in 39 185-ton heats in four melting shops, carbon was knocked down the last 10 points from 18 to 8 in 22½ min., using oxygen through lances or jet devices at the rate of 26,500 cu.ft. per hr. (Weighted averages, again.) Auxiliary advantages, besides the speedup, are that the reaction with oxygen generates heat rather than, like ore, absorbing it, the slag comes to maturity rapidly, and the metal ends-up hot and clean. The time saving is on the order of a half-hour for 0.10% carbon heats, and at least an hour for 0.06% carbon. A debit is the violent splashing of boiling metal and slag, and the large volume of red smoke, either plugging the checkers, pouring out of the electrics, or spreading over the countryside. . . . . If this matter of fume and splashing can be controlled — as by a high velocity jet that blows away the slag and dimples the metal's surface, rather than by a pipe lance thrust into the liquid bath — it appears likely that oxygen can profitably be used for charges of all-hot-metal, or charges that melt down high in carbon. Reducing

Oxygen jet for decarburizing molten steel

high carbon by ore requires patience and inordinate amounts of ore, resulting in heavy blanketing slags (although most operators say that metal from ore is cheaper than metal from scrap). Some 29 oxygen-blown, high-carbon heats observed by the Linde Co. finished in 8 hr. 55 min. (charge to tap) against an average of 12 hr. without oxygen — a reduction of 25% in the furnace time at a cost of 2.4 tons of oxygen per 220-ton heat. Again, at $80 per furnace-hour, as much as $100 per ton could be paid for the oxygen, if its use involved no hidden debits.

THE ECONOMICS of the problem will vary from plant to plant, but it would appear that the relative advantages of using oxygen now arrange themselves in approximately the following order:

Controlling carbon in stainless steels.

Melting heavy scrap (by jet) in electrics or openhearth.

Knocking the last few points of carbon out of rimming steel.

Decarburizing all-hot-metal charges.

Boosting flame temperature during meltdown.

While the items at the top of the list might almost be termed "standard practice" today, the best that oxygen can do (in the items at the bottom), while the metal is in the furnace, can be easily lost in an ordinary plant by delays elsewhere — either in charging, pit work or rolling mill congestion. In fact, heats have been refined in less time than it took to charge the scrap! Present-day openhearth plants have been so closely designed that they get constipated during a very moderate speed-up. It is a much easier proposition to show a 25% saving in time with one furnace on oxygen and 11 on air than it would be to run all 12 and show anything like the same benefit. What is going to happen when the present demand subsides for all the steel that can possibly be made is of course anybody's guess, but economy will be the aim rather than tonnage and the use of liquid oxygen at present prices will probably return to the emergency status except where plant and labor conditions are such that one furnace can be shut down completely and the remainder, using some oxygen, can still maintain an adequate production schedule. . . . . In fact, materials handling is such an important factor that the large plant of the future — built somewhere from the ground up — will probably have no charging machines, but handle everything in process as a fluid. It may be guessed to follow the following pattern: Pressurized blast furnaces, cupolas for melting scrap, sulphur control by alkali or slag in transfer ladles or by manganese in mixer, and *(a)* either bessemers to blow out silicon and some carbon, transferring to openhearths or electrics to remove phosphorus and finish, or *(b)* tilting openhearths to condition metal for medium sized electrics, operating on a 1½ to 2-hr. schedule. In view of the scarcity of fuel oil, one other probability will be mentioned — slagging gas producers. Oxygen, possibly of 90 to 95% purity, will be an essential charge into nearly all these furnaces at some stage or another.

A forecast of future practice

AN OXYGEN PLANT for such an installation would be a very large one, no matter what combination of furnaces is installed. To get some idea of what it *might* be, consider a present-day plant with ten 200-ton openhearths on about half cold metal (because there are more facts known about this operation than any other). When oxygen is used for any purpose in such furnaces it is drawn at a rate of about 40,000 cu.ft. per hr., at pressure of about 125 psi., and at about 95% purity. Owing to lack of synchronism, the demand from the melting shop might be anything from zero to 400,000 cu.ft. per hr. — a situation that is impossible to meet in an oxygen plant, whose heart is a reflux fractionator precisely balanced as to heat and fluid flow. Large storage capacity to absorb off-peak loads will increase plant costs (and carrying charges), but the steel plant would consume, on the average, about 120,000 cu.ft. per hr. with 10 furnaces operating. Presumably a plant for 150,000 cu.ft. per hr. would take care of the fluctuating demand without too much delay to furnaces that are out of step — a rather sizable installation. It will produce metallurgical oxygen for somewhere around $5 per ton. But such a plant will produce one quarter more oxygen in the course of a day than the openhearths consume. That surplus could be diverted to the blast furnaces — just blown into the stoves. Fluctuations in temperature at the tuyeres would be no greater from this extra oxygen than from fluctuations in the air when a cold stove is switched off and a hot one turned on, for even if *all* the oxygen were going to the blast furnaces (zero demand from openhearths) the oxygen in the blast would go from 23% (normal content in air, by weight) to about 25%. Even though the blast furnace superintendent might not want to *pay* anything for this fluctuating surplus, it would be used very efficiently. What this means, of course, is that an integrated steel plant already has a sink for surplus oxygen in its blast pipe system; no further storage for metallurgical oxygen is needed

An oxygen plant for a 10-furnace steel mill

Brazing in Electric Furnaces

By S. DeDomenico
and J. A. Comstock*
Materials Engineering Dept.
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East Pittsburgh, Pa.

Modern brazing has proved itself a reliable method of making strong joints in mass-produced assemblies. Tolerances for fit, and the mutual adjustment of brazing alloys (copper or silver base), fluxes, protective atmospheres, continuous electric furnaces, and equipment for producing the atmospheres — all have been worked out in great detail. The authors make specific recommendations for typical jobs.

WARTIME applications of electric furnace brazing greatly expanded its field of usefulness. Not only have design engineers taken advantage of this modern method for forming and fabricating in order to obtain mass production and minimum cost, but new designs have been built which could not have been otherwise fabricated. At the same time, induction and flame heating were more and more used for brazing metals and alloys, especially with low melting brazing materials, such as silver solders and phosphorus-copper. Today's interest in brazing is also extended since it will offset, in part, recent increases in costs of labor and material experienced in many operations done by more conventional methods.

This paper evaluates *furnace* brazing as distinct from brazing by local heat. The electric furnace is especially suitable for furnace brazing since no muffle is required to maintain the correct atmosphere. However, a very highly reducing atmosphere may require a muffle to get away from the contaminating effect of the porous brickwork in the furnace lining. Methods for sealing a brick-lined chamber with material noncontaminating to furnace atmospheres are important future improvements yet to be discovered. Muffles are expensive, especially for use at elevated temperatures, due to their initial cost and relatively short life.

By maintaining suitable furnace atmospheres many metals and combinations can be brazed together without fluxes or oxidation; the work is clean and bright as it comes from the furnace. This is especially important for copper parts where the high brazing temperature would otherwise cause pronounced surface effects.

Furnace heating (in distinction to localized heating) has two important characteristics — *(a)* control of uniform rate of heating throughout the various sections of the piece, and *(b)* accurate control of temperature. These are essential for preventing distortion (which may be caused by uneven heating of adjacent sections of a piece, setting up internal stresses) as well as for preventing overheating and damage to the work when brazing close to its melting point. Accurate temperature control may also be important as affecting the physical properties of the work in controlling grain size, hardness, and reactions with furnace atmospheres. The ability to hold the work at the desired temperature is often desirable in brazing pieces having extensive joint areas, to allow time for heating through, permit the brazing material to penetrate the entire joint uniformly where high strength and pressure-tight joints are required, or heat conductivity is low.

The above have to do with work requiring slow and precise heating. On the other hand, some work may be put through a furnace at such a rate that brazing is obtained before the more massive parts of the assembly attain uniform furnace temperature, and still produce satisfactory filleted brazed joints together with a high rate of production.

*Mr. Comstock is now with Morse Chain Division, Borg-Warner Corp., Ithaca, N. Y.

By heating the work slowly and thoroughly in a furnace all joints are brazed simultaneously regardless of their inaccessibility, unsymmetrical shape, depth or number. By proper selection of brazing materials a desired heat treatment may be given the work by controlling the brazing cycle and furnace atmosphere to normalize, carburize, or even harden steels.

The above characteristics which distinguish electric furnace brazing from brazing by local heat (induction or flame) are illustrated in the engravings accompanying this article.

showing dissociation pressures of the oxides formed on various solid metals.* Included in the chart are dotted lines for the oxygen partial pressures in equilibrium with CO_2/CO and H_2O/H_2 mixtures typical of industrial furnace atmospheres such as Types 102, 302 and 501. The lines for Types 102 and 302 are parallel; other lines for other atmospheres of differing component ratios may be drawn by shifting the lines up or down an amount equal to twice the logarithm of the new to the old ratio. Thus, the oxygen partial pressure of Type 102 ("Exogas") with pCO_2/pCO of 0.5 is

Table I — Typical Component Ratios and Costs of Furnace Brazing Atmospheres

Code No.*	Westinghouse Designation	Manufacture	Dew Point	pCO_2/pCO	pH_2O/pH_2	Cost per M Cu.Ft.†
101	Lean Exogas	Nearly complete combustion of a fuel gas with air.	+60° F.	16.4	2.4	80.05 to 0.30
102	Rich Exogas	Partial combustion of a fuel gas with air.	+60	0.5	0.12	0.10 to 0.40
302	Endogas	Very rich mixture of a fuel gas and air, re-formed.	Zero	0.005	0.0037	0.15 to 0.45
501	Ammogas	Dissociated anhydrous ammonia.	−65		0.00005	1.25 to 4.00
	Hydrogen	Deoxidized and dried gas.	−65		0.000037	1.50 to 10.00

*American Gas Assoc., Information Letter No. 9 to Industrial and Commercial Gas Section, Sept. 23, 1946.
†Based on methane at 40¢ per M cu.ft.; electricity at 1¢ per kw-hr.; water at 5¢ per M cu.ft.; ammonia at 3.5¢ per lb. in tank car lots and 15¢ per lb. in cylinders.

Furnace Brazing Atmospheres

Furnace brazing lends itself to the joining of most common structural metals and alloys, both ferrous and nonferrous. Those metals and alloys whose oxides are readily reducible in available furnace atmospheres at brazing temperatures may be furnace brazed without the use of flux pastes. Table I gives the typical analysis and approximate cost of various furnace brazing atmospheres.

Benjamin Lustman of Westinghouse Research Laboratories has prepared a chart, Fig. 1, p. 73, 100 times richer in CO_2 than the ratio in Type 302 ("Endogas") having pCO_2/pCO of 0.005. The logarithm of 100 is 2. Doubling this we find the two dotted parallel lines to be 4 units apart on the vertical scale.

Having such a line on this chart for the given atmosphere, a metal heated in that atmosphere will not oxidize if the dissociation pressure of its oxide is greater than the oxygen partial pressure of the gas atmosphere — that is, if the plotted point falls above the line for the atmosphere. Thus, zinc will not oxidize in Type 501 ("Ammogas") above 1000° F. (540° C.), whereas it will oxidize below this temperature.

By referring to Fig. 1 it will be noted that copper, bismuth, nickel and cobalt do not oxidize

Table II — Commercial Brazing Alloys

Trade Designation	Composition						Melting Range	
	Cu	Ag	Zn	Cd	Sn	P	°F.	°C.
Copper	99+						1980	1083
Cu-Ag-Sn	84	8			8		1735 to 1805	945 to 985
Cu-Ag	50	50					1430 to 1560	778 to 850
"Phos-copper"	93					7	1300 to 1425	704 to 800
Eutectic	28	72					1432	778
"ETX"	34	50	16				1285 to 1425	695 to 775
"Sil-Fos"	80	15				5	1190 to 1300	643 to 704
"Easy-Flo"	15.5	50	15.5	18			1160 to 1175	627 to 734

*For a complete discussion of the resistance of metals to scaling see Dr. Lustman's article in *Metal Progress* for November 1946, p. 850. Figure 1 in this article was taken from that issue.

in an atmosphere of Type 102 at any temperature. The curves for this gas and iron are almost identical, but iron does not oxidize at brazing temperatures in Type 102 due to the reducing effect of the H_2O/H_2 proportion, which offsets the oxidizing effect of CO_2/CO at elevated temperatures. However, Type 302, which costs but little more, is used advantageously to produce consistently brighter work due to its greater tolerance for contamination at all temperatures. Its higher carbon pressure also makes it desirable for use with steel when decarburization is to be avoided. Likewise, molybdenum and tungsten are not oxidized on heating and cooling in Type 302.

As noted above, solid zinc oxidizes on heating up to 1000° F. and cooling in Type 501 or in deoxidized and dried hydrogen, but zinc alloys such as brass and certain silver brazing alloys are not oxidized in these atmospheres.

Chromium metal is oxidized on heating and cooling in Types 101, 102, 302 and 501 but stainless steels containing chromium with or without nickel are not oxidized in Type 501 or dried hydrogen atmospheres, free of oxygen.

Silicon, titanium and aluminum oxidize at all temperatures and, if present as alloying elements in amounts of 1 to 2%, require special precautions in brazing.

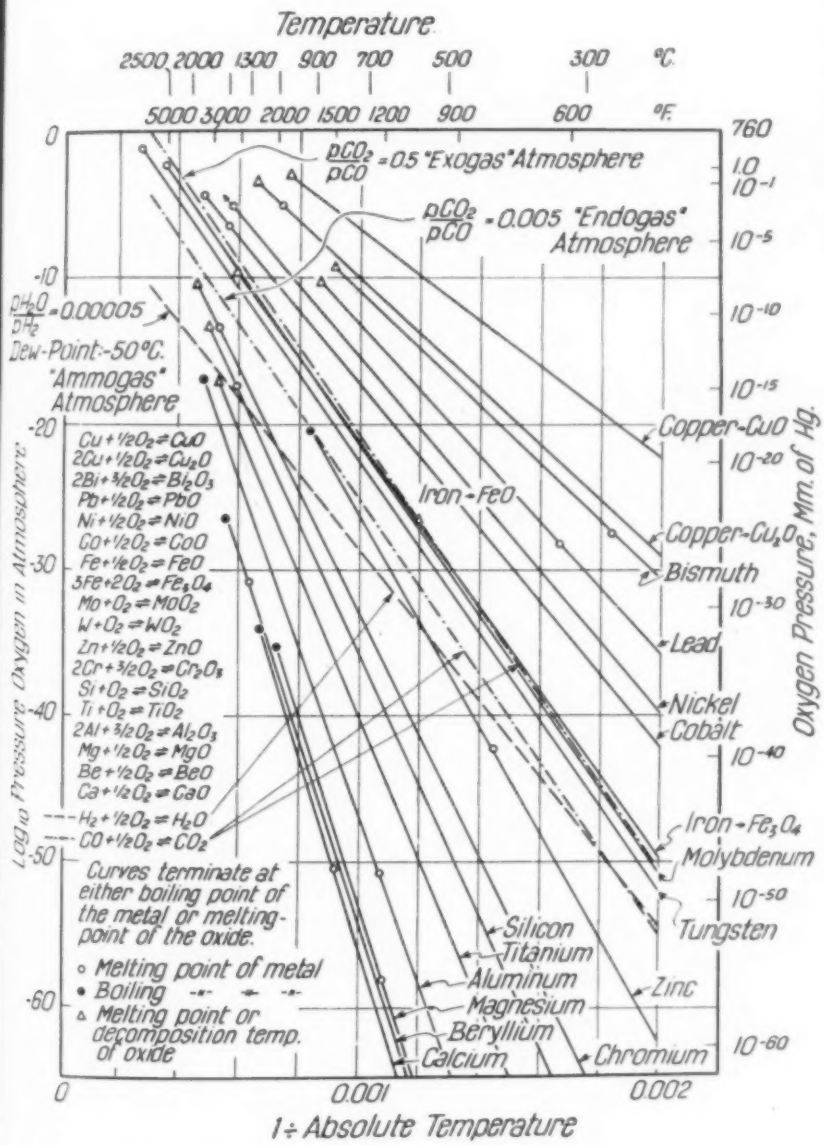

Fig. 1 — Dissociation Pressures of Oxides Formed at Various Temperatures on Several Common Metals. (Lustman)

Strength of Brazed Joints

Table II, p. 72, shows a variety of fusible alloys available for brazing. The suitability of a particular brazing alloy for a given application is generally determined by its melting temperature, its wetting ability and its fluidity. Under clean, nonoxidizing conditions, with respect to both the molten brazing alloy and the solid metal to be joined, capillarity draws the molten alloy into the joint, under suitable conditions of fit, and alloying takes place to produce a strong bond. There are a few combinations, however, which produce harmful alloying effects; for example, the formation of a brittle iron phosphide, or intergranular penetration of some alloys by silver.

Regarding the *strength* of brazed joints, simple lap joints in shear will average between 24,000 and 40,000 psi., depending on the clearance in the joint, the strength increasing as the clearance diminishes. This is true of joints brazed either with copper or silver alloys. Copper gives the highest strength joints when the fit is from zero to 0.002 in. interference. The best penetration of the joint is also obtained within these limits, due to the high fluidity of molten copper.

Although the joint strengths obtainable with silver alloys are comparable to those obtained with copper brazing, the desirable type of fit is not the same. A slight clearance is necessary, due to the lower fluidity of the silver alloys at brazing temperature. This clearance should be in the range of 0.001 to 0.003 in.

In using phosphorus-copper alloys a fit of 0.001 in. interference to 0.003 in. clearance is acceptable, but the strength of these joints is relatively low.

When copper and silver alloy brazed joints are tested in tension, the strength will often be found to exceed the tensile strength of the metals joined and will usually approach the tensile strength of the metal as-brazed.

Due to the higher melting point of copper, joints so brazed can be subsequently heat treated without damage. Any heat treatment required for steels brazed with silver alloys must be simultaneously carried out with the brazing operation. Copper brazed joints have higher strengths at elevated temperatures than do silver brazings, which often has an important bearing on their application.

Metals and Alloys Brazed

S.A.E. Steels — Generally speaking, low-alloy steels such as S.A.E. compositions are readily brazed in atmospheres either of Type 101, 102 or 302. No flux is required for copper brazing. Silver brazing in these atmospheres requires the use of a flux if the brazing alloy contains zinc; Type 501 and hydrogen do not.

Types 302, 501 and hydrogen are used when decarburization cannot be tolerated. Types 101 and 102 require that the component parts be copper plated before brazing, if *all* decarburization is to be prevented. An example of the latter is a bearing bracket for a contactor in which the pin is carburized, then copper plated before assembly with the bracket. This assembly is subsequently hardened by quenching from the brazing furnace, and cadmium plated over the coppered surface for appearance.

All work comes from the furnace with a degree of brightness in proportion to the reducing power of the furnace atmosphere, being extremely bright after treatment in Type 501 or hydrogen, even though the steel may contain chromium as an alloy.

High Alloys — When decarburization of high-alloy toolsteels is to be avoided in copper brazing and bright work is important, a muffle furnace with Type 501 atmosphere or hydrogen can be used. If the steels are of the air hardening type, it is practical to silver braze and to harden the steel at the same time by selection of a brazing alloy having the proper melting range, using the above-mentioned muffle furnace and atmosphere. The pinion and gear wheel assembly (Fig. 2) used in an air type circuit breaker is a good illustration. The steel is 0.15% carbon, 13% chromium stainless, with a shoulder pinion pressed into the gear wheel; the assembly is then silver brazed at 1830° F. (1000° C.), slightly carburized and hardened all in one operation. Similar treatments are possible when handling dies and molds made of air hardening steels.

Tungsten carbide and stellite tipped tools are brazed either with copper or silver, depending on such factors as subsequent or simultaneous heat treatment of the shank to obtain required physical properties. Choice of atmosphere will depend on the importance of decarburization of the shank and whether or not flux is used.

Alloys of high chromium content, such as stellite and stainless steels, require a muffle furnace with cracked ammonia (Type 501) or hydrogen atmosphere to produce bright work brazed with copper or silver.

Nitriding steels present a special problem due

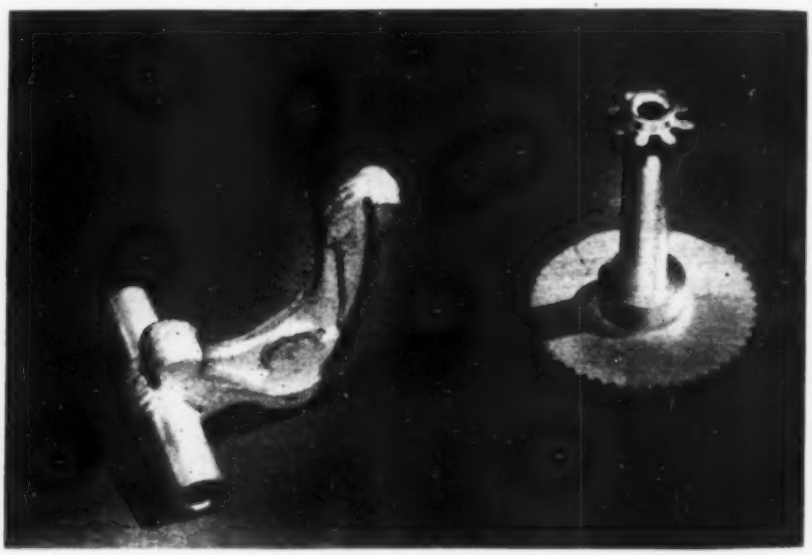

Fig. 2 — Examples of Assemblies Using Some Stainless Steel Parts, Brazed and Heat Treated Simultaneously. At left is trigger assembly, pin and forged arm pressed together, copper brazed in dissociated ammonia (Type 501 atmosphere), subsequently carburized and hardened. At right is stainless steel shouldered pinion pressed into wheel and silver brazed in Type 501 to which a little natural gas has been added so the part is slightly carburized during brazing. No oxidation allowable in either part

to their high aluminum content. They require the use of a flux, even in the most reducing atmospheres available.

Cast irons of all varieties require special consideration due to their high carbon and silicon. Wetting action of the brazing material is improved by flux, or by previous oxidation and reduction, or by previous surface treatment to produce a skin free from graphitic carbon. Copper brazing is limited by the low melting range of some irons; very accurate temperature control is then essential. The lower melting point brazing alloys, such as brass and certain silver-copper alloys, are commonly used. Cast irons grow during brazing, hence dimensional allowance must be made in designing the assembly so as to avoid formation of gaps in the joints.

Nickel and Nickel Alloys — If the assemblies consist of or include nonferrous metals of a higher melting point than copper, such as nickel and its alloys with copper, silver, chromium or molybdenum, copper can be used as the brazing material. Nickel-chromium alloys require the most reducing atmospheres, such as Type 501 or hydrogen. Other alloys may be copper brazed in Type 102. Silver brazing is also applicable (except for Ni-Co-Fe expansion alloys such as "Kovar", which are subject to cracking due to intergranular penetration of the silver). Silver brazing without the use of flux would require Type 501 or hydrogen atmosphere, if the brazing is done with alloys containing zinc.

Copper and Copper Alloys — Probably the widest application of silver alloy brazing is found in the joining of copper, brass and bronze assemblies by the electric furnace method. Only low-melting silver and phosphorus-copper alloys can be used. If assemblies are of copper only, there is no need for a flux in Type 101 atmospheres if the brazing alloy contains no volatile oxide-forming constituent such as zinc. However, if the assemblies contain any steel joints, phosphorus-copper cannot be used due to the formation of a weak, brittle iron phosphide constituent. Furthermore, in assemblies including or consisting of tough-pitch copper, hydrogen embrittlement of the copper must be prevented since it demands an atmosphere which is nearly hydrogen-free. (Oxygen-free copper is exempt from this stipulation.) Lean "Exogas" (Type 101) is commonly used under such circumstances.

A flux is required with brass or bronze unless Type 501 or hydrogen atmospheres are used or special measures are taken to prevent oxidation, such as copper plating before brazing. An example of this practice to avoid the use of a flux which would have been impossible to remove from the inside of the brazed assembly is the water tank for a steam iron (Fig. 3) made of brass sheet and bronze bushings, copper plated and assembled, then phosphorus-copper brazed without flux.

Aluminum bronzes require the use of a flux of great solvent action due to their aluminum content. Aluminum itself can be furnace brazed using a special brazing alloy and a special flux developed by the Aluminum Co. of America. Since the melting point of the brazing alloy is quite close to that of the aluminum, accurate temperature control is essential.

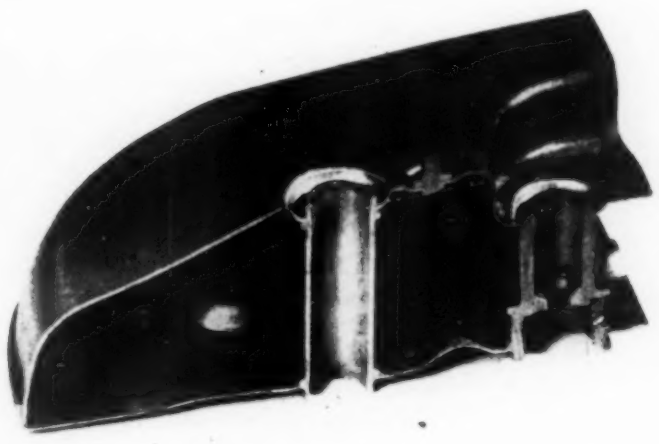

Fig 3 — Section of Water Tank for a Steam Iron, Brazed With Phosphorus-Copper Without Flux, Since Interior Is Inaccessible. Copper-plated brass sheet with tubes and screw-machine parts pressed into holes; Type 101 atmosphere

Joints

One of the requirements of furnace brazing is to maintain proper relations between the component parts of the assemblies while going through the heating cycle. The methods of accomplishing this are various, and many types of joints may be required in a single assembly.

The simplest setup is the so-called gravity contact joint in which the parts are merely laid together and aligned by protuberances or grooves in one or both of the parts, by loose pins, or by fixtures.

Brazing metal in the form of foil may be placed between the component parts during mechanical assembly, or it may be fed, liquid, into the joint by capillarity by the melting of wire

placed in close proximity. A paste which is made by mixing brazing metal powder with lacquer may also be painted on the assembly.

Probably most common is the pin-and-hole assembly. Here a slight press fit would be required to preserve alignment unless the pin can be knurled or the hole peened around the pin. Other methods might be staking the pin, or swaging or peening the end of the pin.

All these methods would also apply to the fitting of tubes or bushings into holes. Also, the tubes might be spun, expanded, or crimped.

If the joint is of the lap or interlocked type, tack or spot welding may be used, or screwing, peening, or fixturing. In this type of joint care must be exercised to maintain minimum clearance between the surfaces to be brazed in order that the brazing material may penetrate into the lap joint satisfactorily.

Notes on Production Equipment

Essentially, the equipment required for the operation of an electric furnace brazing department may be *(a)* an electrically heated furnace chamber with integral chamber for cooling under gas, and *(b)* atmosphere producers for generating the desired type. With these go the necessary power and temperature controlling equipment, alloy trays, fixtures, and material handling devices.

The particular design of furnace necessarily will be determined after consideration of such factors as production rates, size, weight and shape of assemblies, shop space available, cost of equipment, its maintenance and operation, adaptability for other uses, and quality of personnel and supervision required.

Since a brazing furnace may be used for other heat treatments, it is very often located in the heat treating department. However, continuous brazing furnaces used in mass production are commonly designed for brazing specific parts and are located in close proximity to the work as it comes off the machines.

Where a low rate of production is expected and where development work is to be done, the box type pusher furnace is especially suitable. This furnace has a wide range of application as regards size, weight and shape of assemblies to be brazed; its added feature is that it can be used for various other heat treatments of ferrous and nonferrous metals. The initial cost and maintenance are low, due to the absence of complicated mechanisms. The assemblies are placed in suitable trays and manually pushed into the furnace and cooling chamber by rods, and withdrawn from the cooling chamber by hooks.

Where high production is required, and the weight of the assemblies is not prohibitive, the mesh belt conveyer furnace will give automatic control of the brazing cycle and high production. Furnace trays are not especially required here except when necessary to distribute the load over the mesh belt, since the work is usually placed directly on the belt. This furnace has a variable speed mechanism to control the travel of the belt, thus insuring uniform heating and cooling of production parts at the correct rate.

For heavier and larger types of assemblies, the furnace with roller hearth is most suitable. Here also the work is put through the furnace automatically either on trays or — if shape permits — directly on the rollers.

Very heavy assemblies, large in size, can be brazed in a bell type furnace where factors of atmosphere control, rate of cooling, and production requirements are not in opposition.

Where very dry furnace atmospheres ("Ammogas" or hydrogen) are required, a muffle type furnace must be considered, although experimental runs have shown a standard brick-lined brazing furnace can be conditioned by a very long purging period, to maintain moisture in the atmosphere to dew points around −60° F. (−50° C.).

The type of atmosphere-producing equipment will be determined by the brazing operation requirements. If Type 101 or 102 is to be used, a special gas producer for reacting various combustible mixtures of air and gas is obtainable of suitable capacity (250 to 20,000 cu.ft. per hr.) for almost any furnace. Producers of capacities ranging from 150 to 4000 cu.ft. per hr. are also available which re-form rich noncombustible mixtures of air and gas in an electrically heated retort filled with a suitable catalyst. Type 501 is produced by passing anhydrous ammonia through a dissociator comprising an electrically heated retort filled with a suitable catalyst — commercial equipment for this ranges in size from 150 to 4000 cu.ft. per hr. Hydrogen of −65° F. dew point, oxygen-free, is obtained by passing tank or line hydrogen through a deoxidizing unit and then through an activated alumina dryer.

Type 101 atmosphere is noncombustible, as are also the inert atmospheres consisting of 97 to 99% nitrogen. Neither of these is toxic, nor is Type 501 (dissociated ammonia) nor dried hydrogen. The other types of atmospheres (Type 102, 302 and other commercial atmospheres based on natural gas or charcoal) are toxic as well as combustible, so proper precautions as to ventilation, fire control and first aid are requisite for safety of plant and personnel.

National Security in the Atomic Age

ON May 29, the President's advisory commission on universal training reported* that "its members started with a considerable disparity of viewpoint on the degree to which universal military training would contribute to our readiness for war or to the advancement of world amity [but reached conclusions representing] unanimous judgment based on nearly six months of intensive study.

[We are convinced] that the only real security for this country or any country lies in the abolition of war through the establishment of the reign of law among nations. Yet one of the deterrents to the effectiveness of the United Nations is the belief of other nations that the United States is stripping itself of the strength necessary to support its moral leadership. It is apparent from the lessons of history that the only way we can lend authority to our voice in international affairs and inspire confidence in the ability of the United Nations to enforce peace is to maintain armed forces that will defy challenge by any would-be aggressor.

[Pending the arrival of the reign of law among nations] our first necessity is to envisage the possible nature of future war. Long-range aircraft within ten years will be capable of flying at supersonic speeds and traveling at such altitudes that interception by anti-aircraft fire is improbable. While transpolar or transoceanic projectiles are unlikely of perfection within the foreseeable future, guided missiles might be used effectively if launched from planes, submarines or warships at short range. Immensely more powerful weapons have been added through atomic energy and through bacteriological and chemical agents. For not more than ten years can we expect immunity from such an attack because we alone possess the atomic bomb.

[Attack without warning will be] the signal for the start of a war against us; after that is to be expected a large-scale onslaught with atomic explosives against our principal centers of population and production. The coming of war will be cataclysmic in its suddenness and destructiveness. We would have chaos, with communications disrupted, millions of persons sick, wounded and dying, civil disorder and sabotage. [There will be no time] to mobilize, train and equip an effective fighting force. General Eisenhower said that the decision would be determined by our ability to act and react within the first 60 days. Every city, factory and farm would become part of the zone of combat. The prospect is for a decrease in the troops at the fronts, and an increase in the number in the rear as technicians, supply components and for home-defense.

To prevent complete disaster in the first few hours or days, two things are imperative: We must have an airborne striking force of highly trained professional troops, equipped with most advanced weapons and in constant state of alertness to intercept additional attack, to retaliate, to dislodge the enemy from his advanced bases, and to occupy bases for counterattack. Second, and equal in importance, we must have trained men in *every* part of our country ready and able to meet disorder, sabotage and airborne invasion, [as well as to] handle problems of civilian evacuation, medical care, fire fighting, repair of utilities, highways and railroads. Attack may come at any point; no standing army, national guard or civilian organization could assume this responsibility. To meet such a universal attack we must have trained men everywhere.

It is also possible that the final outcome will not be determined by superiority in weapons of mass destruction. Defeat in the future, as always in the past, may have to rely on the cutting of supply lines, the systematic elimination of military objectives, and finally the invasion and occupation of enemy territory. [Therefore] the United States cannot chance facing future warfare without large reserves of men trained and disciplined in the use of weapons and techniques of warfare.

[The commission emphasized that its recommendation for universal military training was only one of several essential activities coordinated with a unified army, navy, and air force composed of professionals. These additional requirements include a first-class intelligence service, industrial mobilization, stockpiling of critical materials, and scientific research and development on an unprecedented scale.]

[As to universal training, it concludes that all boys on reaching 18 or ending their schooling should be given six months of basic military training in camp or aboard ship under conditions specified in much detail, to be followed by another six months' service (or its equivalent) designed to fit them to be specialists, instructors, group leaders or officers. At the trainee's option, this additional duty can be discharged by continuing universal training for another six months, by enlistment in one of the armed services, by satisfactory performance in accredited courses in college or military academy, or three years' service in the National Guard or Organized Reserve.]

We recommend the adoption of universal training because we are convinced that weakness on our part not only involves our country in grave risks but also weakens the United Nations, on which rest our hopes for lasting peace. A weak and irresolute America is an invitation to failure. A strong and resolute America is the best guarantee for our safety and for the success of the United Nations.

*"A Program for National Security", 95 pages plus 13 appendices, U. S. Government Printing Office, price 75¢. The commission consisted of Karl T. Compton, Chairman, president of Massachusetts Institute of Technology; Joseph E. Davies, former ambassador to Russia; Harold W. Dodds, president of Princeton University; Truman K. Gibson, Jr., lawyer; Daniel A. Poling, editor of *The Christian Herald*; Anna M. Rosenberg, industrial relations consultant; Samuel I. Rosenman, former special counsel to the President; The Rev. Edmund A. Walsh, vice-president of Georgetown University; and Charles E. Wilson, president of General Electric Co.

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.

Metallographic Identification of Sigma Phase in 25-20 Austenitic Alloy

By G. N. Emmanuel
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ALTHOUGH the presence of sigma phase in high-chromium ferritic irons has been established and accepted for quite some time, it has only been very recently that the formation of an identical intermetallic compound has been verified in the austenitic stainless steels by X-ray diffraction methods.

Because X-ray work involves equipment not in widespread use and techniques not generally known, it is advisable to have some method whereby sigma can be identified under the microscope with some degree of assurance.

With this thought in mind, a sample of 25-20 Cr-Ni alloy (austenitic "steel") was heated 1000 hr. at 1600° F. to produce sigma in easily discernible amounts.

The accompanying photomicrographs illustrate the effect of various etching reagents and techniques on the appearance of sigma phase under the microscope.

The first series is the result of electrolytic etching with 1 ampere of 6-volt current in 10% oxalic acid. The etching times vary as indicated. Lightly etching (for 6 sec.) sharply delineates the sigma phase. What appears to be structure in the sigma is in reality cracking which is a characteristic of this constituent. Continued etching for 24 sec. brings out the grain boundaries and the larger carbide particles, whereas the sigma is almost completely eaten out. Doubling this time (48 sec.) will outline all the details of the microstructure, and no advantage is therefore to be gained by further etching.

Figures 4 to 6 show another field of the same alloy etched in aqua regia. Etching for 5 sec. in this more active reagent is enough to attack the sigma phase and to outline the carbide particles. In 20 sec. the sigma patches appear as voids, and the austenitic grain boundaries are fairly well developed. Continued etching emphasizes these

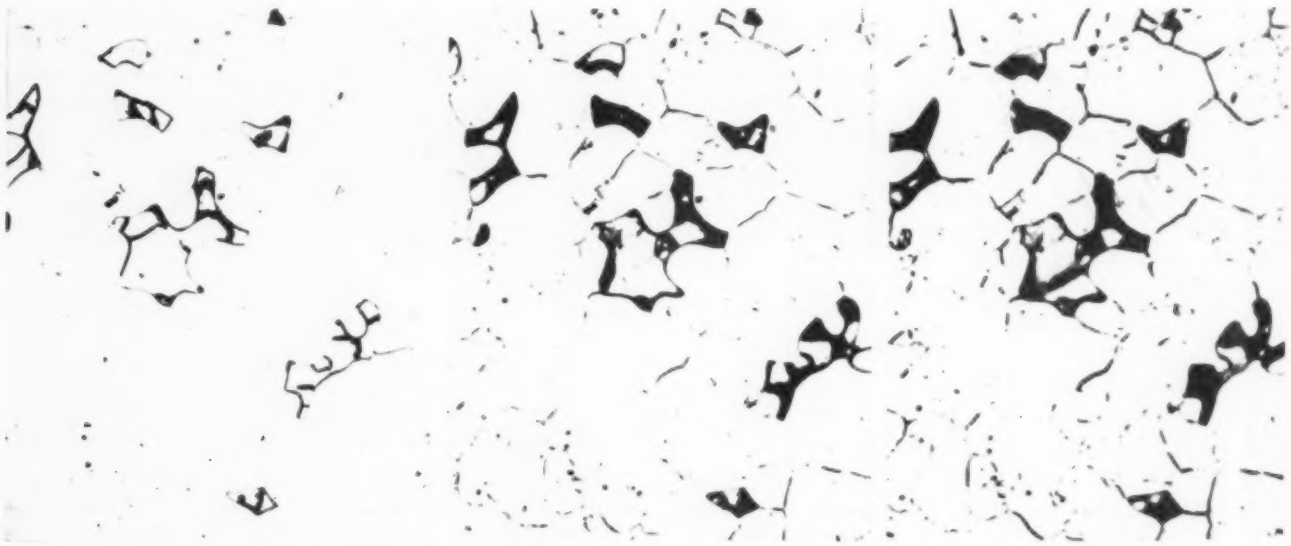


Fig. 1 to 3 — Electrolytic Etch in 10% Oxalic Acid for 6, 24 and 48 Sec. Respectively. 500 ×

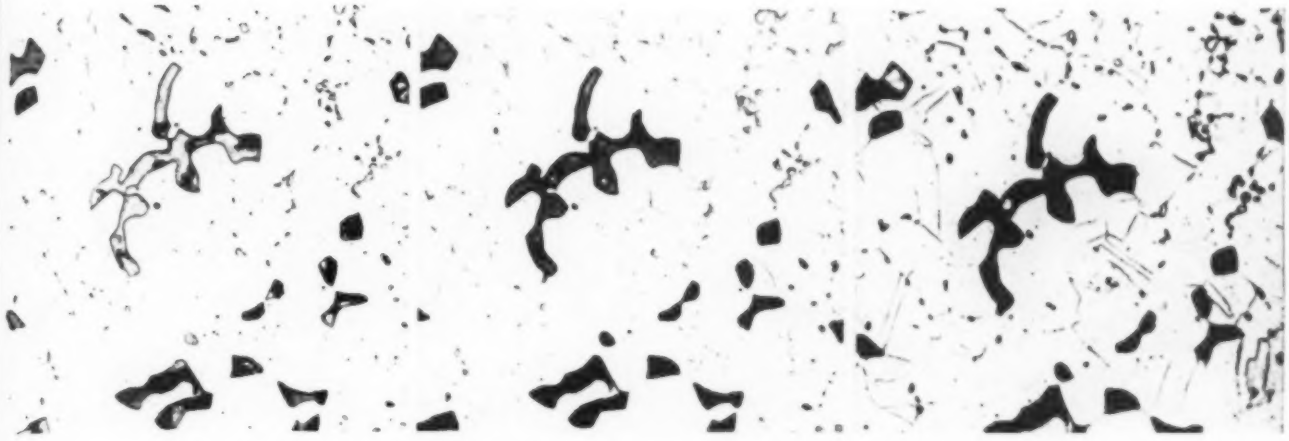


Fig. 4 to 6 — Aqua Regia Etch for 5, 20 and 35 Sec. Respectively. 500 ×

features; the sample may be considered to be fully etched in 35 sec.

Murakami's reagent at 70° F. (10 g. $K_3Fe(CN)_6$ plus 10 g. KOH in 100 ml. water) brings out the carbide particles clearly (Fig. 7) whereas the sigma phase is only faintly attacked, if at all — a condition that persists even up to 3 min. etching. Modifying the reagent by concentration (30 g. ferricyanide, 30 g. caustic, 60 ml. water) reverses the action — sigma is etched, carbides and austenite are unetched. Figure 8 at 400 × clearly shows this action. The characteristic brittle cracking in the sigma phase is rather clearly shown under polarized light; the boundaries and cracks appear in light and brilliant colors. When viewed under white light, the sigma patches are yellow, as though stained with iodine. At 1200 diameters, elements of the structure of the sigma phase may be discerned (Fig. 9). Eberbach tester indicates a hardness of about 1000 on the Vickers scale; the austenitic groundmass with its scattered carbides is 250 hard.

Another differentiation is by heat tinting. On heating a polished specimen in air at 1200° F. and examining at intervals up to a total of 20 min., the austenite will be observed to pass through the temper colors ahead of the sigma, and the carbides resist oxidation longest. Thus, after heat tinting for 20 min. and examining at 250 diameters under white light, the austenite will be a mottled blue-green, the sigma orange, and the carbides remain white.

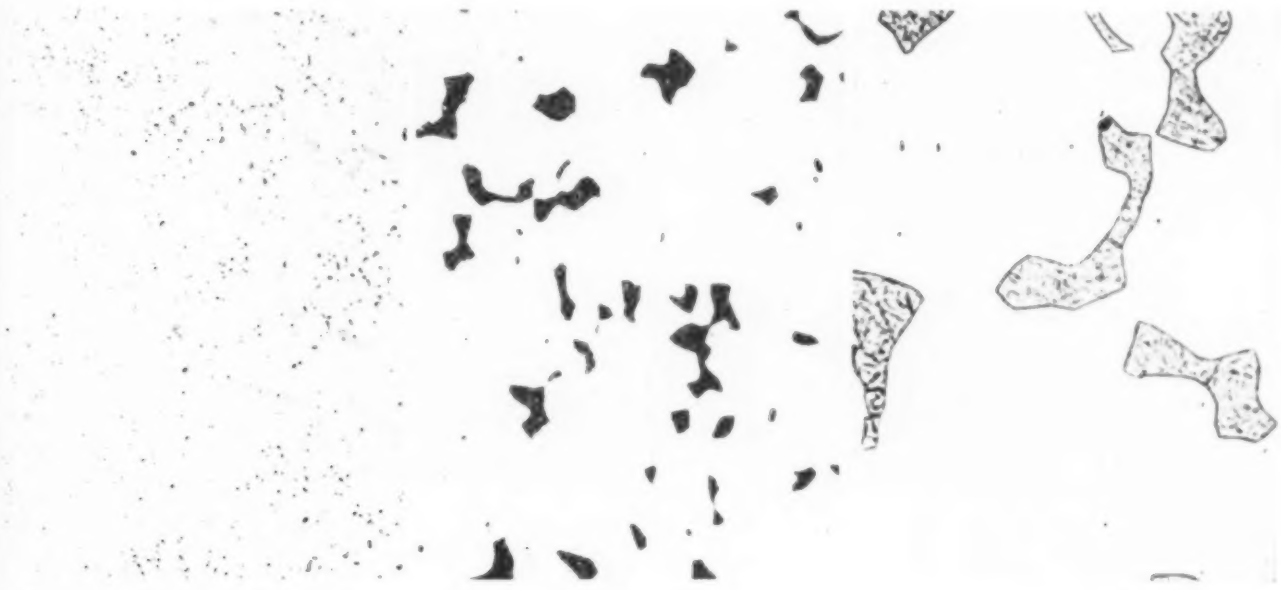


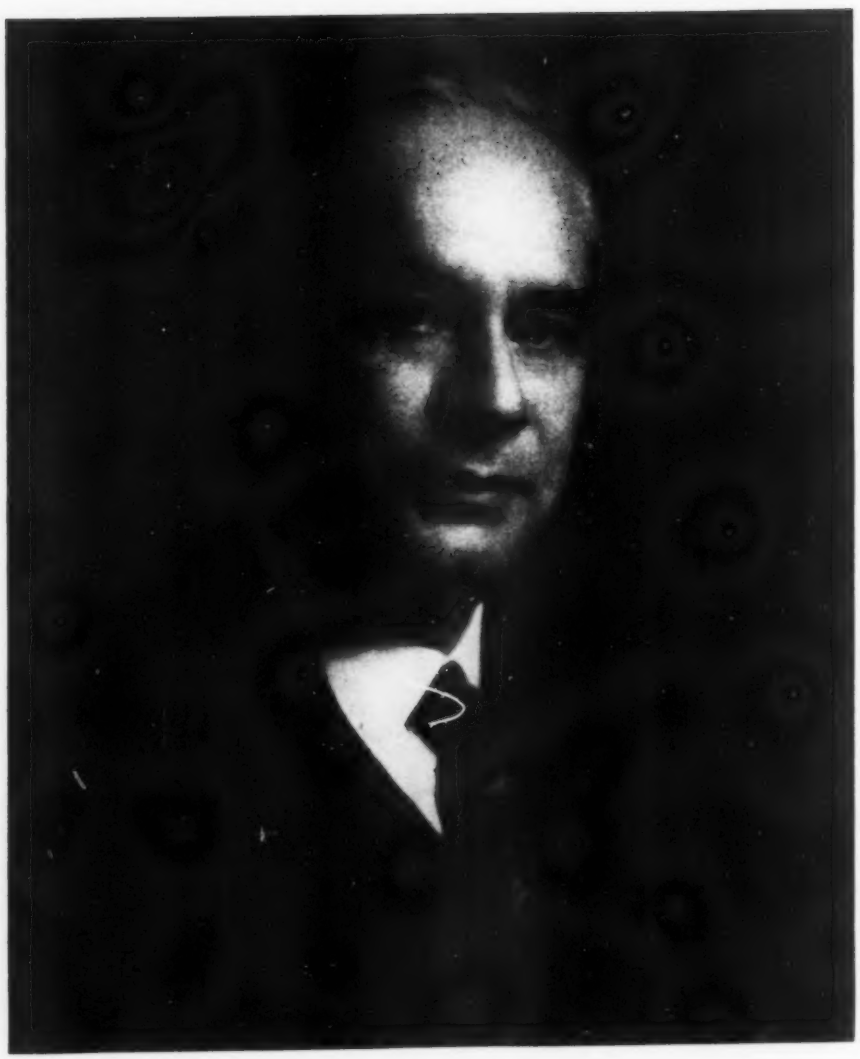
Fig. 7 — Carbides Developed by Murakami's Reagent in 15 Sec. at 70° F. 200 ×

Fig. 8 — Sigma Developed by Concentrated Murakami's Reagent in 3 Sec. at 70° F. 400 ×

Fig. 9 — Same Etch as Fig. 8; Photographed at 1200 × to Show Structure in Sigma

Rufus Eicher Zimmerman

1946 A.S.M. Medalist
for Advancement
of Research



IN THE MANNER of certain quiz programs, the following clues could be given for identification of the man who is the 1946 recipient of the American Society for Metals' medal for advancement of research:

1. One of his outstanding characteristics is his apparently unlimited capacity for hard work. His average working day is well over ten hours, and he carefully budgets his time so that there are no wasted moments. The almost monastic austerity of his office bears testimony to the fact that it is a place for work rather than for visiting and idle conversation. Where the weekly commuting between his Pittsburgh and New York offices would have worn down the average individual, he appears to thrive on it.

2. He has had a guiding hand in many outstanding metallurgical and chemical developments in the steel industry during the last two decades, notably stainless steel, electrolytic tin plate, and high strength low-alloy steels.

3. He approves for publication approximately 350 papers a year, and has passed on the manuscripts of such outstanding metallurgical books as Bain's "The Alloying Elements of Steel", Grossmann's "Principles of Heat Treatment" and Austin's "Flow of Heat in Metals". He coordinates all metallurgical and chemical research and development for United States Steel Corp.

4. The friends at his residence in Short Hills, N. J., look upon him as "the great commuter", and he is well acquainted with all the conductors, porters and waiters on the Pennsylvania Railroad sleepers on the regular runs between New York City and Pittsburgh.

RUFUS EICHER ZIMMERMAN was born in Mt. Pleasant, Pa., on Nov. 26, 1886. He attended Franklin and Marshall College in Lancaster, graduating ΦΒΚ in 1908 with a Ph.B. degree, and continued his education at Massachusetts Institute of Technology, receiving his Sc.D. degree in 1911. In 1938 he received the honorary degree of Doctor of Science from Franklin and Marshall College; in 1942 Thiel College conferred upon him the degree of Doctor of Laws.

He was an instructor in physical chemistry at M.I.T. for a period of three years after graduation; during this time he got interested in physical metallurgy. In 1914 he joined the research laboratory of the American Sheet and Tin Plate Co. in Pittsburgh, Pa., as a research associate. There he reported to BRADLEY DEWEY, who was then in charge of the research laboratory, although of about ZIMMERMAN'S age. This chemist, who has since reached a pinnacle in American engineering, profoundly influenced him and deepened his interest in the scientific aspect of metallurgical problems.

In 1915, RUFUS ZIMMERMAN was made assistant director of the Research Laboratory, and was appointed acting director of research of American Sheet and Tin Plate Co. in 1917. He became director of research in 1919 and three years later was appointed assistant to vice-president for operations, a position which he held until 1932. In that year he went to New York as assistant to the president of United States Steel Corp., and was made vice-president of the corporation in 1933. At the beginning of 1938, with the establishment of the United States Steel Corp. of Delaware, with offices in Pittsburgh, Dr. ZIMMERMAN was elected a director and member of the executive committee and was appointed vice-president for research and technology, a position which he now holds.

During the first world war, he was consulting chemical engineer for the United States Bureau of Mines, working on problems of gas defense. During the recent war he was a member of the advisory committee to the Quartermaster General, U. S. Army, for which activity he received a citation. He is a member of the National Engineers Committee of Engineers' Joint Council, the Advisory Committee on Standardization of the Department of Commerce, and of the Research Committee of the Army Ordnance Assoc. He was a member of the metallurgical advisory board of the Carnegie Institute of Technology, a term member of the corporation of Massachusetts Institute of Technology, and from 1941 to 1943 president of the American Standards Assoc. He is now a trustee of Hood College; a member of the advisory board of Princeton Engineering Assoc.; and a member of the board of trustees of his alma mater, Franklin and Marshall College.

He also gives unsparingly of his great abilities to several engineering societies, such as the American Chemical Society, the Electrochemical Society, the American Institute of Mining and

Metallurgical Engineers, and the American Society for Metals. In the latter organization he is active on the committee on education.

Is it surprising that a man engaged in the discharge of so lengthy an array of duties should find little time for hobbies? Yet RUFUS ZIMMERMAN likes to talk about them. He is fond of working with tools, and harbors the ambition of having a completely equipped woodworking shop some day, where he can indulge in fine cabinet-making activities. (His father was in the furniture business, and he says he was practically brought up in a woodworking shop.)

He does not care much for golf, "because it made liars of so many of my friends, and because there was no course near my early home when I should have learned the game". Perhaps this is a blessing to his wife (*nee* ANNA BURNS of Lancaster) and family, for with his penchant for thoroughness there is no telling what the golf bacillus would have developed! He hates bridge but plays when forced into it. He contends that it fails to be a relaxation, since it is just a continuation of the daily menu of research problems.

Like many scientists he is very fond of music. He was one of the charter sponsors of the famous May Beegle concerts in Pittsburgh long before the Pittsburgh Symphony Orchestra was founded. He likes to attend Metropolitan Opera performances in New York City, but regrets that he can enjoy them so infrequently during the season.

He is an inveterate smoker, having a fondness for good Havana cigars — although he is also partial to those stogies which are manufactured in his old home town of Mt. Pleasant. (He privately admits to a weakness for sauerkraut and onion sandwiches, which is understandable for a man raised in the lush and beautiful Pennsylvania Dutch country.)

The scope of his activities in the far-flung empire of research is indeed extensive and includes diversified areas. To mention but a few: The latest project is the establishment of a research laboratory to study the problems of beneficiation of the low grade iron ore existing in the Mesaba range in astronomical tonnage. This will be operated by the Corporation's subsidiary, the Oliver Iron Mining Co. in Duluth, Minn. He was also actively engaged in investigations relating to the welding of steel ships, the evaluation of processes for the production of sponge iron, the disposal of steel mill wastes, the development of fabricated steel for house construction, the perfection of electrolytic and hot-dipped tin plate, the heat treatment of rails, the improvement of deep-drawing steels, the improvement of blast furnaces, and the use of oxygen gas in commercial metallurgical processes. In the last 30 years he has been granted a number of patents along these lines.

His friends and associates feel that DR. ZIMMERMAN's greatest achievement is the encouragement and support he gives to research, better expressed in the words of the ⚙ citation: "He has ever practiced the best principles of modern organization, with maximum delegation of authority, opportunity for initiative and recognition of achievement." His coworkers admire his keen memory, his composure and calm, his simplicity, and a modesty which almost borders on self-effacement. However, a sense of humor, coupled with a wide experience in human relations and the art of getting things done with a minimum of friction, makes him a top-notch executive whose sound and balanced judgment based on varied technical experience is sought widely.

"Research men should be the tallest men on earth," he said, in conclusion of an interview, "because they have to keep their heads in the clouds and their feet on the ground. And if there is no 'romance' in research, there will be no progress. Moreover, nobody should be put down as a 'queer' because he has done something bizarre in the search for new technological development."

No more fitting tribute could be paid RUFUS EICHER ZIMMERMAN, who typifies the progressive executive, than is expressed in these words taken from the dedication of Jeffries and Archer's book, "The Science of Metals":

> "The maintenance and extension of our industrial and economic civilization depend on the coordinated work of groups of individuals whose efforts are directed toward increase in efficiency, improvement in quality of existing products, and development of new products. Men who have good character and ability and who in addition have an understanding of human nature are usually selected to guide the activities of these groups. Because these executives direct the expenditure of money and energy, they determine to a large extent the industrial and economic progress of the world. Executives are progressive in proportion to their ability to select men and stimulate them in obtaining and utilizing fundamental information for the betterment of mankind."

These words mark the character of the man who carries the ⚙'s most recent award of the medal for advancement of research. For the atomic age, give us more men with these attributes, more men like ZIMMERMAN.

HANS J. HEINE

Recent Developments in Magnesium

By J. C. McDonald
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The first part of a paper, illustrated with a profusion of lantern slides, read in March before the Western Metal Congress at Oakland. In this portion, Mr. McDonald calls attention to important improvements in foundry techniques, pleads for simplified designs, and cites some examples of test programs from the many that have been pursued during wartime, that furnish the data whereby these simplifications can be confidently adopted. In a subsequent portion he will describe some new alloys of great interest.

IN THE PAST few years a number of developments have taken place in the magnesium industry which give promise not only of making better materials available, but also of lowering their cost. Some of these developments were closely connected with the large expansion of the industry during the war. Although present production is well under the wartime peak, the estimated consumption for 1946 was on the order of 20,000,000 lb., which is four times the average of the last prewar years. In 1946, for the first time in a decade, structural applications outstripped the nonstructural in the amount of magnesium used. (The latter include such items as cathodic protection, pyrotechnics, alloying with other metals, and Grignard reagent.)

Summarizing briefly, we may say that production developments have occurred in both the wrought metal field and the casting field. A broader understanding has been gained of those characteristics of the metal which render it so suitable for so many applications. New alloys now in the experimental stage of development will increase its usefulness in the structural field. In the nonstructural field many electrochemical uses have arisen. Some interesting new laboratory techniques are now available which assist the work of the metallographers.

There have been a number of improvements in wrought metal production directed toward decreasing direct labor cost with a consequent decrease in the over-all costs. The scale of melting operations has been greatly increased through installation of reverberatory furnaces; maintenance costs and safety are also considered to be better than the older melting pots. Instead of the old hand dipping operations with ladles, pumps are now used for conveying molten metal. Alloying may be carried out in the reverberatory furnace or in a steel pot into which the molten magnesium is pumped; ingot or billet molds are then filled by pumping from the pots. Billets for subsequent conversion into wrought products are made in continuous fashion on a direct casting machine. Slabs for the rolling mills are now largely cast directly rather than being extruded from a round billet.

It has been realized for a long time that very good design efficiency can be achieved by adoption of much larger forgings than the usual size of press is capable of handling. During the war some work was done to show what might be possible in this direction, and forged booms for cargo hoists in the form of a channeled hinge about 5 ft. long and 10 in. wide were made experimentally at that time. There has since been erected in Worcester, Mass., a forging press of 18,000-ton capacity on which even larger forgings are being made. A still larger press was in existence in Germany, which during the war made side frames for trails on field artillery, a triangular shaped piece nearly 8 ft. long and about 2 ft. high at the axle end, intricately ribbed and bossed.

It has been realized for a long time that the most economical manufacture of magnesium alloy sheet will require the large continuous mills commonly seen in steel and aluminum plants. The possibility of handling magnesium on such equip-

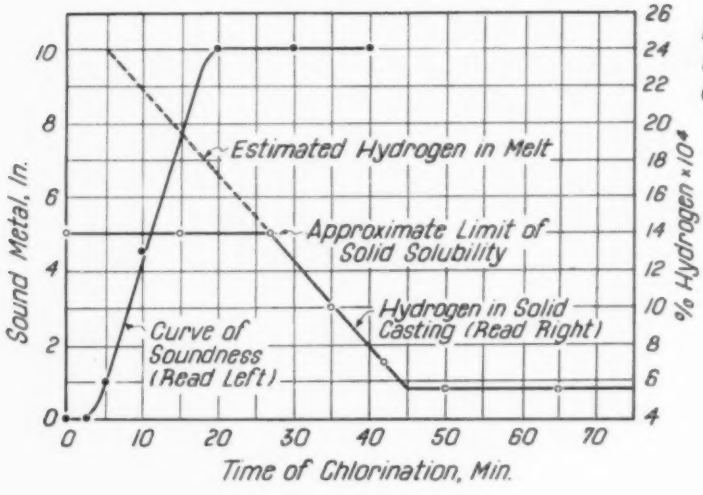


Fig. 1 — Effect of Time of Chlorination on the Amount of Hydrogen Remaining in Cast Metal and Its Effect on Microporosity

ment has now been demonstrated. In addition, magnesium shapes have been rolled on the type of mills already in existence. Commercial application of these developments will lower the cost of magnesium sheet and shapes appreciably.

Turn now to a consideration of casting techniques. The chlorination of melts is now being widely practiced as a good cleansing procedure as well as a method of eliminating hydrogen. Microporosity has been decreased somewhat by keeping hydrogen in the melt to a minimum. Under the conditions of the experiment illustrated in Fig. 1, 20 min. of chlorination resulted in a cast panel of maximum soundness. Chemical analyses of the product showed that this treatment reduced the hydrogen in the melted metal to about the level of its solid solubility in magnesium. There was then no excess hydrogen to be liberated during the freezing process which would prevent the formation of a completely sound casting.

Another innovation of great importance in foundry production has been a new type of slot gate, as shown in Fig. 2. The molten metal is poured into a tubular sprue filled with steel wool; from this the metal feeds into the casting through a slot. Not only is it easier to achieve complete soundness, but the amount of metal discarded in risers is reduced.

Superheating of magnesium alloys to achieve a minimum grain size as cast is still standard practice in most foundries. Considerable experimental work has been devoted to the production of fine grain through treatment with various carbonaceous compounds; as yet, however, the process has not been worked out on a production scale.

An interesting scheme of interest to fabricators of articles of magnesium sheet has come from the welding engineers, namely, the superposition, on the alternating current feeding the welding arc, of a high frequency alternating current. Stabilization is apparently produced, resulting in less heating; in consequence smaller welds can be made and thinner sheet welded.

The ease with which magnesium sheet may be deep drawn has been amply demonstrated. In this

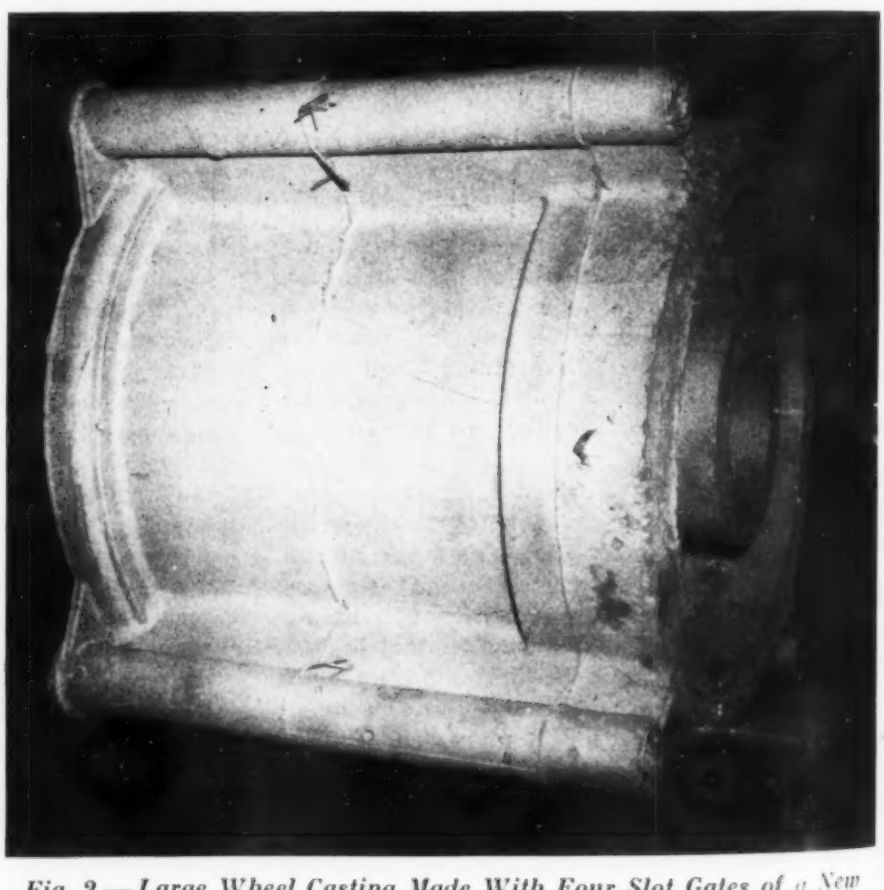


Fig. 2 — Large Wheel Casting Made With Four Slot Gates of a New Type. Before the metal is poured the sprues are filled with steel wool

respect the metal is almost in a class by itself. Through the use of heated tools, heated sheet can be drawn to great depth and intricacy. A representative part is a rocket carrier box, made during the war, a rectangular receptacle 28½ x 10 in. opening and with almost vertical walls 12½ in. deep — a most difficult draw.

Developments on fronts other than production have been equally noteworthy. A better realization has been gained of those characteristics of magnesium which peculiarly fit it for a variety of applications. Because of its low density and the strength of its alloys, articles may be designed in a simple way which not only facilitates fabrication, but causes each part of the structure to carry its proportional share of the load. The airplane designer calls this the "monocoque". The modulus of elasticity of magnesium is lower than that of other structural metals, by virtue of which a high degree of resilience is obtained. Some simple experiments compare the resilience of magnesium to other sheet metals. (See Fig. 3.) A 6-in. circular specimen, firmly clamped at the circumference, was loaded through a tup of 3 in. diameter. The tup was pressed down until a permanent dent 0.2 in. deep remained. The energy required was measured and plotted against thickness, figured to the equivalent thickness of magnesium sheet of equal weight. Figure 3 shows that the low density and low modulus of magnesium more than compensate for its lower tensile strength per sq.in.

A great deal of attention has been given to the fatigue resistance and notch sensitivity characteristics of magnesium alloys because of their importance in most services. Such a mass of data has been accumulated that only a few of the main conclusions can be presented here. The laboratory results indicate that the magnesium alloys are comparable in these respects to the higher strength aluminum alloys.

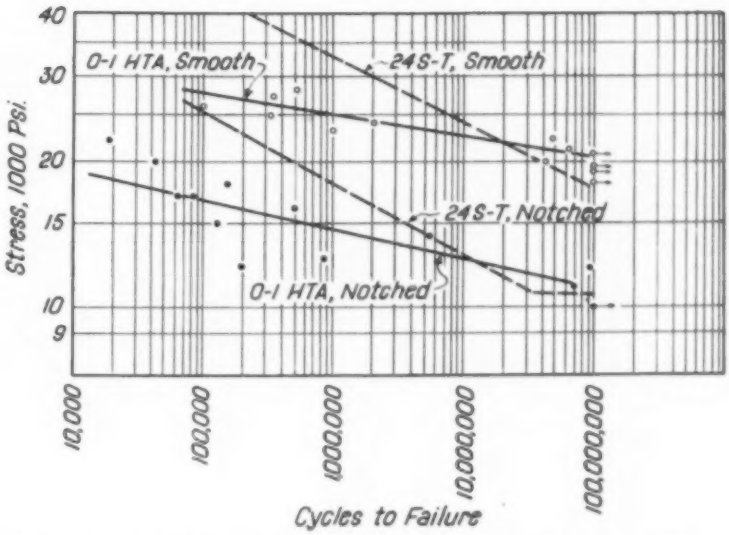
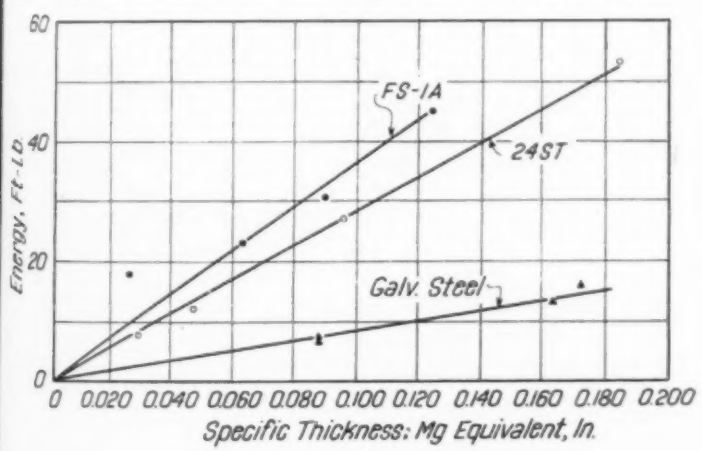


Fig. 4 — Rotating Beam Fatigue Tests on Extruded Bars, Plain and Notched (Stress Concentration Factor 2), for Magnesium Alloy O-1HTA and Aluminum Alloy 24S-T

Fig. 3 — Relative Resilience of Magnesium Alloy FS-1a, Aluminum Alloy 24S-T and Galvanized Steel, Sheets Graded in Thickness to Be of Equal Weight per Sq.In. Sheet 6 in. dia., tup 3 in. dia., dent 0.2 in.



One study of the notch sensitivity used a tension test of a strip containing three equally spaced round holes, thus simulating rivet holes in sheet. Magnesium alloys Ma, Mh, FS-1a, FS-1h, J-1a and J-1h were included in this study, as well as aluminum alloys 24S-T and Alclad 75S-T. If the strip contained three $\frac{3}{16}$-in. holes and its effective width was reduced by 10%, the remaining metal (through the effects of stress concentration) was weakened from 2 to 15%, depending on the alloy. As the proportion of width occupied by hole increased until half the metal was drilled away, this loss due to stress concentration gradually disappeared in all alloys; the remaining metal generally carried from 100 to 105% of the stress expected of an undrilled strip. However, the "specific strength" of one of the magnesium alloys, Ma, rapidly increased as the proportion of metal lost to rivet holes increased; the ultimate strength of the remaining metal when the distance between edges of rivet holes equaled the diameter of the holes (half the metal lost to rivet holes) rose to 115% that of undrilled sheet.

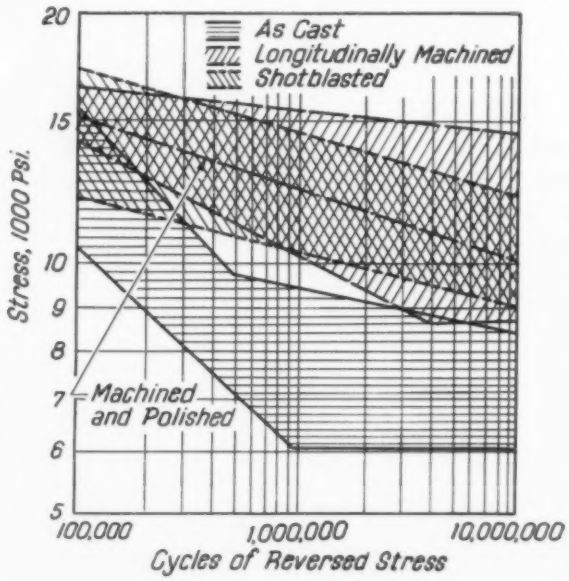
Another series of tests involved the bending of notched strip; the energy absorbed prior to rupture was determined. The radius of the base of the notch and sharpness of the notch was varied, and

again the conclusion is that the magnesium and aluminum alloys in sheet form react in similar fashion to this type of stress concentration.

Of the many types of fatigue tests made, only two can be reported here. Comparing the lines on Fig. 4 we see that the chief difference between the magnesium and aluminum is in the slope of the S-N curves for both smooth and notched bars. This is a characteristic difference observed in practically every kind of fatigue test that was run, not only rotating beam but also plate flexure and axial loading tests, with or without stress concentration. The notch sensitivities of the materials are usually comparable. The chief difference observed was in cast materials having extremely sharp notches. Aluminum was less sensitive than magnesium to this condition.

Another interesting study concerns the comparative effect of shot blasting on the fatigue resistance of cast magnesium and aluminum plates. As may be seen in Fig. 5, the magnesium cast alloys as a group were benefited very considerably by shot blasting; aluminum castings of a typical alloy (195-T6) were also improved but only to the extent of raising their endurance limit on the order of 20%. It was also shown that the effects of machining on the cast panels of the two materials were quite different. While the fatigue strength of the magnesium was raised, that of cast aluminum was lowered at least 15%. The S-N curves for aluminum, in this investigation, also showed the characteristic steep slope noted in Fig. 4.

Fig. 5 — Effect of Surface Finish on Endurance of Cast Magnesium Alloys. Scatter bands include tests on 9x3x⅜-in. panels, sand cast, tested in reversed bending



Returning now to the question of simplified design, there is no doubt that intricate shapes would be avoided irrespective of the choice of material if they did not often result in saving of weight. Magnesium's low density, however, enables one to dispense with complicated ribbings and reinforcements without penalty. A positive gain is, in fact, effected by virtue of the decreased manufacturing cost. It should be obvious that stress concentrations can be better eliminated with smooth contours rather than sharp lines. A good example is the casting illustrated in Fig. 6. At top left is shown the diaphragm section of the original aluminum diaphragm. When this engine was redesigned for magnesium the first modification was that shown in the middle figure. The wall under the bearing was found to be inadequate and the final design may be seen at the lower right. The final magnesium crankcase weighed about the same as the original aluminum crankcase, but the engine developed about twice as much power without service failure.

Fig. 6 — Design Evolution of Airplane Engine Crankcase Diaphragm, From Aluminum at Top Left to Magnesium at Bottom Right. Weight the same for engine of double the power

One cannot picture the advantages of simplified structures with-

out mentioning the enormous amount of study given them by designers of aircraft structures. The early wings and fuselages were metal skeletons, tied and braced together, and covered with fabric stiffened with varnish-like "dope". As the size, power and speed of the ships increased, the fabric was replaced with alclad aluminum, and the designer then rightly expected this metal covering to take some of the loads in service. The aim has been constantly to simplify the structure, not only to reduce its manufacturing cost, but to clear the interior of members which interfere with movement of crew and installation of necessary auxiliaries, and to save weight by making each part carry its share of the stresses.

These trends in design have resulted in the "semi-monocoque" construction wherein the stressed skin of a wing, for example, is stiffened longitudinally by numerous small Z bars or bulb angle extrusions. Fore and aft are placed diaphragms at perhaps 12 in. spacing, these diaphragms conforming to the cross section of the wing and lightened with appropriate openings. Main shear stresses are carried by a stout web running lengthwise of the wing, and a set of ribs near the trailing edge.

All-magnesium wings of this sort have been in service for a number of years on Navy trainers flying at Gulf of Mexico bases. The wing is stronger than its aluminum prototype and about 14% lighter. This illustrates what can be done when the objective is maximum strength regardless of complexity of manufacture.

What can be done if the design is a true monocoque is shown in Fig. 7. This wing, an experimental part for a Navy PV-1 ship, is still in the erection jig, and has had one side removed to show the simplicity of the internal construction. Note that there are no longitudinal stiffeners riveted to the skin. Neither is there a longitudinal shear web down the center. The diaphragms are few in number and, for the most part, are hoop-like in construction.

In this there has been a tremendous simplification and consequent reduction in manufacturing costs by using relatively thick (although not heavy) magnesium sections and sheet. These advantages are gained without loss in strength-weight ratio; the all-magnesium monocoque wing is slightly heavier than its aluminum prototype, but also somewhat stronger. Part of the reason for this, of course, is that — weight for weight — a magnesium strut or compression member is about 50% greater in cross section than the aluminum member of the same general shape. This extra metal gives the strut a correspondingly higher resistance against buckling or crumpling, and hence a marked superiority in carrying compressive loads. If the member is an aluminum plate, it must be adequately stiffened before the high potential strength of the aluminum alloys can be effectively realized.

Fig. 7 — All-Magnesium Monocoque Aircraft Wing in Assembly Jig, Top Skin Sheet Removed to Show Simplicity of Construction

Magnetic Particle

Inspection of Weldments

A conference reported
By S. L. Henry
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Milwaukee, Wis.

A method of spreading information that apparently is gaining popularity is the conference organized by a commercial firm wherein its own engineers — but especially outside experts — discuss the capabilities and limitations of the firm's product, to the edification of a general audience. Such a successful discussion was held early in May before 200 welding engineers by Magnaflux Corp. in Chicago. Mr. Henry says it was a lively meeting, quite uninhibited, and stimulating. Not everyone went away convinced that all questions are satisfactorily answered, as yet.

INSPECTION by the magnetic particle technique was developed as a workable tool by the late Alfred V. deForest in 1929. It simply consists of attaining a properly oriented magnetic field in the iron part to be inspected and applying fine magnetic particles which are held at the defect by the leakage field created by the discontinuity. There are various means of creating the magnetic field. An alternating current is used in parts which are being inspected for surface defects only. For subsurface defects, direct current is used. For weld inspection, full-wave rectified alternating current with an initial surge of higher current is used. (Half-wave rectified current is the latest development and maximum sensitivity is claimed for it.) Magnetic particles are applied as a dry powder by a blower or bulb. The dry powders, either black, gray or red, are usually used on welds for maximum sensitivity. In some instances the powder is suspended in a light oil and flowed over the part.

Weld inspectors most commonly use prods for contacts, applied several inches apart on the weld seam. The desired current is thus passed through the weld and induces a circular magnetic field with the lines of flux transverse to the length of the weld deposit. A nearly automatic method is being developed for a pipe mill. Pipe varying in diameter from 6 to 20 in., with ¼ to ⅜-in. wall thickness will be automatically magnetized, dusted with the powder, the excess powder removed and reclaimed for continued use. The pipe will travel at a rate of 50 to 100 ft. per min., and it is planned to scan the weld with a photo-electric cell which will remove pipe from the production line which shows indications. The weld can then be examined by an inspector who will decide whether the indications are cause for rejection.

A word of caution was thrown in by W. E. Thomas of Magnaflux Corp. The method is frequently too sensitive. Welded parts or assemblies have been rejected on the basis of indications which were not detrimental. As in other methods of inspection, this has resulted in an attitude of "damn the method or damn the inspector". This difficulty can be overcome by a sensible approach and evaluation of the inspection problem. It is definitely up to inspection to prove its worth in dollars and cents as reflected in better production and a better product.

Experience is needed in interpretation. This can be gained only by using the correct technique, trepanning or cross-sectioning at an indication, and thus evaluating the defect in relation to its effect on service life. Also a knowledge of the design, stresses, vibration, impact, service and consequences of failure would be needed. Thus, in highly stressed aircraft parts very rigid standards are required. In other applications, stresses in weldments may be so low that anything but the most obvious defects would not impair service.

Nondestructive Weld Inspection

J. J. Chyle and A. Cota of the A. O. Smith Corp. summarized and evaluated the available methods for weld inspection, such as X-ray, magnetic particle, and supersonic testing. Their

remarks applied particularly to heavy welds such as found in pressure vessels. Included was an original investigation to evaluate the relative merits of X-ray and magnaflux in the inspection of the first layer and subsequent layers as built up in a deep groove. Included were tests on very heavy plate (solid construction) as well as other vessels for extra high pressure constructed of several layers of steel plate, welded into successive jackets. Magnetic particles could not find subsurface defects in girth welds on layer vessel construction (when applied with existing equipment) possibly due to magnetic flux leakage at the layers. In the solid construction, defects could be found as far as three layers or passes below the surface. The only surface preparation in this test was wire brushing to remove the slag. The defects found were intentionally made unfused lip lines, slag inclusions and porosity. X-rays readily interpreted the indications for both types of construction.

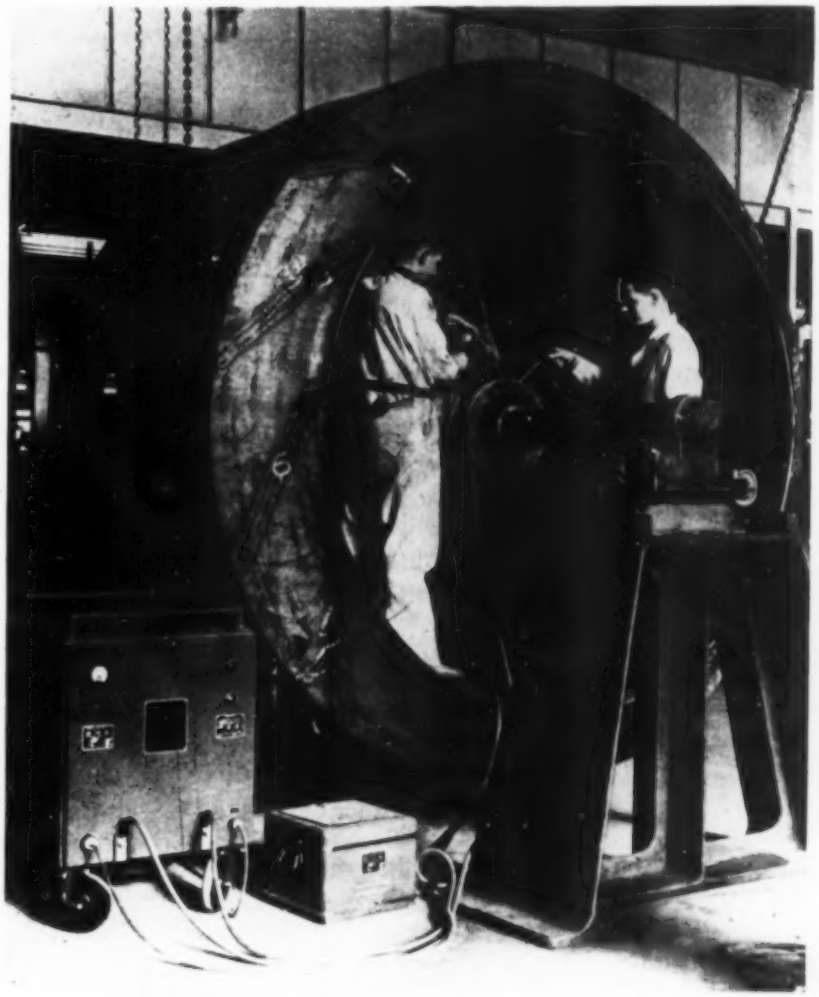
The obvious advantages of the magnetic particles over X-ray or γ-ray for this particular type of inspection would be the low cost, lack of delays in production and adaptability for repair inspection. The advantage of X-ray inspection would be, of course, maximum sensitivity and penetration of thick sections.

A lively discussion was held on the effect of stress annealing in either producing defects or increasing the sensitivity of inspection. Several instances were cited where magnaflux found new defects on previously inspected welds after annealing. Defects were found 0.4 in. below surface in the as-welded condition, and after stress anneal to a depth of $\frac{5}{8}$ in. The problem is serious in that stress annealing is necessary after any repair welding is done on high pressure equipment.

Introduced during the general discussion were methods of maximum sensitivity for finding subsurface defects. One such method was the introduction of an alternating current field at 45° to the main direct current field. The main purpose was to excite the magnetic particles to greater mobility. As an indication of the sensitivity of the magnetic particle technique, an instance was cited where Lüder's lines were revealed by the pattern of magnetic particles. Likewise, due to the difference of permeability at the edge of the heat-affected zone, a distinct pattern of magnetic particles is sometimes found.

Field Inspection

R. J. Love of the Pressure Vessel Research Committee of the Welding Research Council led a discussion on pressure vessels. Four gas holders were described which were field erected to a diameter of 34 ft. and a length of 206 ft. and operating at 55 psi. The heads were made of $\frac{7}{16}$-in. and the shells were made of $\frac{11}{16}$-in. steel, conforming to A.S.T.M. specification A 212. Due to the geometry of the tank, water testing was impossible because of the weight of water. The gas holders were air tested at 60 psi., after all weld seams, 3000 ft. in length, had been inspected both inside and out by the magnetic particle technique.



Magnetization With Prods to Inspect Welds in a Large Air Blower During Fabrication

It is necessary to remove scale or slag before inspection, and grinding, sandblasting or wire brushing is suitable. In field inspection it is not necessary to remove thin paint coats (except magnetic oxide pigments) if contact can be made through prods.

High Pressure Piping — W. B. Bunn, Jr., of the M. W. Kellogg Co., led the discussion on welds in high pressure piping. He traced the rise in operating pressures and temperatures to the present-day steam at 1650 psi. and 1050° F. Under these conditions it is imperative that the welds in this piping, which is made of air hardening alloy steels, be free of discontinuities. At these temperatures the design must necessarily be based on creep strength rather than on ultimate strength. (In some instances austenitic stainless alloy steel is used; because of its nonmagnetic characteristics other methods of inspection must be used.) In the alloy steels, arc burns with the prods must be avoided; if the surfaces of the welds and prods are clean and free of oxides, no trouble should be encountered from this source by a careful operator.

Machinery Weldments

J. W. Owens, of Fairbanks, Morse and Co., led the discussion of machinery weldments. He interjected the thought that it is the moral responsibility of the welding engineer that any defect, particularly a crack, be removed if it could possibly lead to failure of the assembly. Of the various types of discontinuities that may be found in welds, the most serious *is* the crack because it is a stress raiser.

A very important joint in machinery weldments is the fillet type; however, fillets should be used where no tension stresses will occur at the root. In fillet welds made with unfused root openings, inspection by use of alternating current gave best results with no confusing pattern due to the root openings. In this type of weld Mr. Owens was not interested in small subsurface porosity or inclusions of slag. It is usually possible to design a machinery weldment so stress relief is not necessary; thus many of the operations common to pressure vessels are unnecessary.

Weld Repair

Wm. E. McKenzie, of the U. S. Naval Gun Factory, led the discussion on the role of magnetic particle testing after weld repair. Defects in castings, forgings and plate material may frequently be removed by grinding or chipping without the necessity of repair welding. If repair welding is necessary, the repair should be inspected after welding and after stress relieving. The inspector should consult with the designer and welding engineer before the repair is made; in many instances the defects found may not affect the service, and costly repairs may then be avoided.

It was mentioned that the magnetic particle method does not indicate lamination in plate material except at any cut edge where it exists. Mention was made of the use of alternating current to differentiate between laminations and segregations. Segregation usually is not shown by alternating current but is shown by direct current.

Zyglo Principles and Application

"Zyglo" utilizes a penetrating oil which will enter an opening of 4 microns. The liquid may be wiped or sprayed on the part, or the part dipped in the penetrant; the excess is then washed off with water and after drying, a developing powder is dusted on. On viewing the part with the so-called "black light" (near ultraviolet), the fluorescent penetrant which seeps out of a crack or void is easily seen.

The method has been used for inspecting such parts as carbide tool tips, stellite coated valves, and pressure vessels lined with austenitic sheet. The latter were inspected in the field. The previous testing method consisted of drilling and tapping a hole in the lining, and introducing air pressure between the backing plate and lining; soap solution was then applied to discover any leakage. Another scheme is to force ammonia gas between the plate and lining instead of water, and use litmus to indicate the leaks. The old method was costly and slow; the tapped hole had to be plug welded, and in some instances leaks occurred in the plug welds.

A. Robinson, of General Electric Co., discussed the application of Zyglo to the inspection of welds in fabrication of gas turbines for aircraft. It was found the best medium for examining welds in buckets and bucket wheels. The parts are thoroughly washed, thoroughly rinsed in a special tank and then dipped in the penetrant. The developer is then applied and after 15 min. the weld is examined in a booth lighted with the near-ultraviolet light. The 4-in. shaft ends, made of magnetic alloy steel, are flash welded to the bucket wheel, which is an austenitic alloy; this weld is also inspected with Zyglo. Interpretation of each type of defect shown was originally made with the aid of macro and micrographs of the cross sections at the defects.

Modified Type 405 Stainless Iron

— a Satisfactory Lining for Petroleum Refinery Vessels

By Merrill A. Scheil*
Director of Metallurgical Research
A. O. Smith Corp.
Milwaukee, Wis.

Modified Type 410 stainless iron (11 to 13% chromium, 0.08% max. carbon) has been successfully used since 1936 in over 100 vessels in American petroleum refineries operating within the range of 500 to 1000° F. that caused early embrittlement failure of the 17% chromium-iron linings. Two years later Modified Type 405 (13% max. chromium, 0.08% max. carbon, 0.20 to 0.30% aluminum, 0.02% max. titanium or columbium) was introduced and has since become all but standardized for this purpose, hundreds of vessels being in satisfactory service. There are six known instances of embrittlement after long exposure to high temperature. Analysis shows that five of these were off limits of chemistry; one was an example of stress corrosion.

IN AN authoritative article describing the "High Chromium-Irons" in the April issue of *Metal Progress*, H. D. Newell, chief metallurgist of Babcock & Wilcox Tube Co., presents a comprehensive view of the physical and mechanical properties of these alloys ranging from 12% chromium up to 25%. Since their most important uses are based on ability to resist hot, corrosive liquids and gases, Mr. Newell rightly paid a great deal of attention to the *stability* of the alloys, by that meaning the retention of their original properties even after years of severe service. It was found, for example, that Type 430 (17% Cr) — despite its excellent resistance to corrosion by petroleum products containing hydrogen sulphide — was unsuitable for service between 700 and 1000° F. because it hardened and became quite brittle in as short a time as three months. Frequently the lining opened up cracks as wide as $\frac{3}{16}$ in. which could not be repaired by welding, owing to the cracking tendency of this alloy when *local* heat is applied. Fortunately most of these vessels were in petroleum refineries and had acquired a somewhat self-protective layer of coke, so the carbon steel shells were not too badly damaged; most of them were relined in the field with more satisfactory material.

Even though the cause of this so-called "885° embrittlement" is still obscure, its presence is now well recognized, and there is little likelihood of such difficulties with this alloy from this cause in the future. Likewise, it is no drawback to the extensive use of this alloy in nitric acid equipment and for exposures at less than 700° F. — in fact, more than three quarters of all the tonnage of high chromium-irons made in the United States is Type 430.

Even though we recognize that the study of failures, such as the above, is a very good way to determine the circumstances wherein a metallurgical product will be quite safe, it is also true that a single unexplained failure of material working under supposedly safe conditions will cause considerable worry until the reasons for the trouble are clearly known. For that reason unusual importance attaches to the instance cited by Mr. Newell (page 624, April *Metal Progress*) where Type 405 strip (0.08% C, 13.18% Cr, 0.18% Al) in

*Acknowledgment is made to my colleague, R. A. Huseby, research metallurgist, who collaborated in many of the investigations mentioned in this report.

the lining of a hot oil separator became quite brittle after five years' service at about 735° F.

Types 405 and 410 stainless irons (11.5 to 13.5% Cr, with other elements below well-defined limits) are the ones to which the oil industry turned when the 17% Cr Type 430 proved itself unsuitable. A. O. Smith Corp. alone has fabricated over 250 pressure vessels lined with either Type 405 or 410 stainless iron for combating corrosion in refinery processes, and about half this number are lined with a Modified Type 405 (the type containing aluminum). Over 100 vessels are operating in the temperature range from 800 to 900° F. with about the same number in service at temperatures between 500 and 750° F. Vessels in coke drum service at 850 to 900° F. have been in service with Type 410 linings since 1936 and those with Type 405 linings since 1938, without any indication of embrittlement in service. We have used a Modified Type 405 almost entirely since 1938 in preference to Type 410; the reasons for this choice are probably worth outlining,* since they will explain the limitations we have placed on the chemical composition of this type for this service.

Unless such linings resist heat and corrosion they are useless. Even an ideally noble metal, however, would be noncommercial if it could not be readily fabricated in large units. Finally, the structure must be stable.

Let us examine these items, one after another.

Corrosion Resistance of 12% Cr-Fe

In view of the well-grounded opinion that oxidation resistance is measured by chromium content, other conditions being equal, refinery engineers were hesitant to accept the lower chromium Type 410 for the higher chromium Type 430 which became brittle at 885° F. Short of service experience, it was hard to predict with surety. However, the Huey test is well recognized as giving a fairly accurate comparison of the corrosion resistance of one alloy against another, or one heat treatment against another, in oxidizing media, and the results of such tests (Table I) indicated that Type 405 (low carbon, 13.4% chromium, plus aluminum) corroded at two to three times the rate of Type 430 — but this rate was probably quite low enough for the petroleum equipment.

Much more revealing and convincing are tests wherein cross-welded sheets and strips held in a stirrup form (stress-corrosion samples) are placed directly in the operating stream. Results of such a set after 6250-hr. exposure are summarized in Table II. They showed that the performance of the 12% chromium alloys compared very favorably with the 17% alloy on the basis of both penetration rates and susceptibility to pitting attack. (As would be expected, the 18% chromium, 8% nickel alloys show a definite superiority.)

Proof of the pudding is in the eating. With 10 to 12 years of experience with several hundred vessels, the petroleum refineries have reported very little trouble. (The few instances which have come to the writer's attention will be analyzed later.) Experience to date shows that either of the Modified Types 410 or 405 have given satisfactory service, handling some of the most corrosive crudes in reaction, flash and coke chambers, and in separator services where operating temperatures range from 800 to 950° F. Either grade has been satisfactory for bubble tower, fractionator and exchanger shell services where temperatures between 500 and 750° F. are involved. At temperatures below 500° F., frequently found at the top of some towers, weak acids form (such as hydrochloric, if the crude is salty). Under these conditions the straight

Table I — Huey Tests on Straight Chromium Alloys
Inches penetration per year during three 48-hr. periods in boiling 65% HNO_3

Type:	405	410	410 + Mo	410 + Cb	430
Analysis:	0.07 C 13.4 Cr 0.28 Ni 0.27 Al	0.12 C 12.0 Cr 0.28 Ni	0.09 C 12.3 Cr 0.33 Ni 0.46 Mo	0.06 C 12.7 Cr 0.50 Cb	0.08 C 17.0 Cr 0.12 Ni
Mill annealed					
1st period	0.090	0.822	0.228	0.311	0.030
2nd period	0.100	0.715	0.228	0.462	0.031
3rd period	0.100	0.808	0.169	0.428	0.047
Average	0.097	0.782	0.208	0.400	0.036
Heated 2 hr. at 1200° F., furnace cooled to 900° F., cooled therefrom in air					
1st period	0.095	0.473	0.183	0.246	0.034
2nd period	0.098	0.413	0.181	0.262	0.032
3rd period	0.090	0.431	0.165	0.277	0.033
Average	0.094	0.439	0.176	0.262	0.033
Heated 1 hr. at 1550° F., furnace cooled to 1200° F. and held 2 hr., furnace cooled to 900° F., cooled therefrom in air					
1st period	0.089	0.527	0.271	0.025	0.038
2nd period	0.089	0.427	0.302	0.246	0.037
3rd period	0.089	0.479	0.250	0.282	0.048
Average	0.089	0.478	0.274	0.184	0.041

*A full discussion was given by W. J. Jackel in *Corrosion* for June 1945, in a paper entitled "The Role of the Straight Chromium Stainless Steels for Refinery Vessel Linings".

Table II — Corrosion* and Pitting† of Typical Alloy Lining Materials Exposed 6250 Hr. in Petroleum Refinery Service

Alloy Type‡	Located in Crude Stabilizer												Separator Tower			
	Set 0 — Above Tray 1 H_2S; 150° F., 100 Lb.				Set 1 — Below Tray 15 Gasoline; 325° F., 105 Lb.				Set 2 — Above Tray 16 Vapor; 375° F., 95 Lb.				Set 3 — Above Tray 1 Vapor; 690° F., 390 Lb.			
	X-Welded		Stressed		X-Welded		Stressed		X-Welded		Stressed		X-Welded		Stressed	
	Rate*	Pit†	Rate*	Pit†	Rate*	Pit†	Rate*	Pit†	Rate*	Pit†	Rate*	Pit†	Rate*	Pit†	Rate*	Pit†
501	0.0043	0.01	0.0059	0.01	....	....	....	....	....	....	....	....	....	....	....	....
410	0.0020	0.03	0.0024	0.02	0.0042	0.02	0.0054	0.01	0.0038	0.03	0.0049	0.01	0.0063	0.01	0.0089	Nil
405	0.0017	0.05	0.0032	0.01	0.0036	0.03	0.0042	0.025	0.0048	0.02	0.0055	0.025	....	....	....	....
430	0.0023	0.02	0.0039	0.03	0.0041	0.03	0.0053	0.05	0.0015	0.025	0.0099	0.025	0.0011	0.01	0.0020	0.025
304	0.0009	0.025	0.0015	0.015	0.0010	0.03	0.0015	0.03	0.0048	0.025	0.0050	0.03	....	....	....	....
347	0.0006	0.025	0.0011	0.02	0.0008	0.04	0.0014	0.02	0.0115	0.01	0.0115	0.01	0.0004	0.01	0.0007	0.01
316	0.0001	0.03	0.0003	0.01	0.0002	0.02	0.0004	0.03	0.0123	0.03	0.0106	0.01	0.0003	0.04	0.0005	0.025

*Corrosion rate figured to penetration in inches per year.
†Depth of deepest pit in inches.
‡For analysis see Table III.

Table III — Chemical Analysis of Alloys Tested in Table II

Type	Alloy	C	Mn	Si	Cr	Ni	Other
501	5 Cr	0.06	....	....	4.92	0.13	....
410	12 Cr	0.12	....	....	12.58	0.43	....
405	13 Cr + Al	0.07	....	....	13.44	0.28	0.27 Al
430	17 Cr	0.08	0.41	0.45	17.01	0.12	....
304	19-9	0.05	0.45	0.28	19.19	8.95	....
347	18-10 + Cb	0.08	0.33	0.36	18.53	10.40	0.75 Cb
316	18-13 + Mo	0.07	1.39	0.33	17.43	12.76	2.79 Mo

chromium grades will be actively attacked, making it necessary to put other alloys in these locations.

Fabrication by Welding

One advantage of Type 430 (17% Cr) as to fabrication was that the low-carbon alloy is completely ferritic at all temperatures and therefore there were no hardened areas alongside spot welds attaching the lining to the steel vessel, or along the seams in the joints between sheets, plates and fittings. Twelve years ago, during the transition from 17 to 13% chromium steel for refinery vessels, the commercial specification for low carbon was usually 0.12% max. As is well known (and shown in Fig. 3 of Newell's article), carbon extends sharply the "gamma loop" of the iron-chromium equilibrium diagram. Since the gamma loop for negligible carbon (0.01 or 0.02%) extends as far as 12 to 15% chromium, 0.12% carbon would form enough austenite during the heat of welding so the metal would harden during subsequent cooling. That this is true is proved by Fig. 1, showing hardness traverses across single bead butt-welds used to seal adjacent sections of stainless iron linings in carbon steel pressure vessels. (Welding of these pieces was with 25% Cr, 12% Ni electrode.)

These tests showed that where extensive welding is to be employed on the linings, the analysis with 11 to 13% Cr, with an addition of 0.20 to 0.30% aluminum, has great advantage for its low air-hardening characteristic.

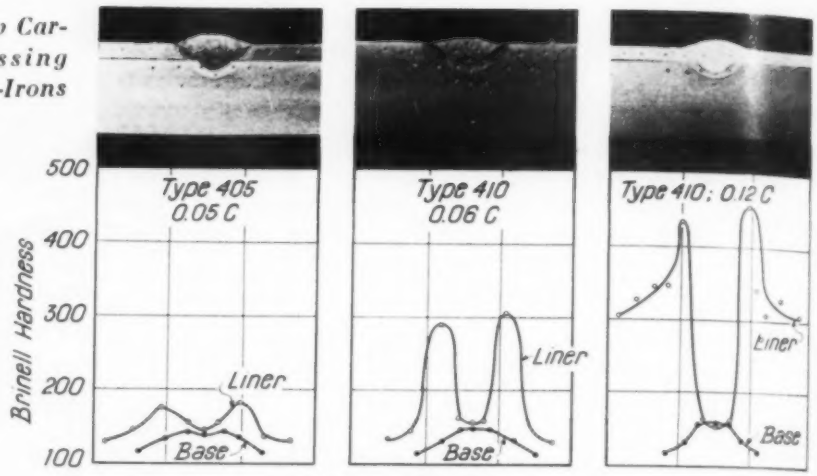
Quenching — Similar information is derived from experiments wherein samples of the various types are quenched from various hardening temperatures. (Water quenching from 1600° F. and higher gives a moderately harder sample than air cooling.) Such experiments are plotted in Fig. 2. They supplement aging experiments (to be described later) in showing the desirability of lowering the carbon to 0.08% max. (a decided improvement over the composition with 0.12% carbon), keeping the chromium on the low side (ordering the 11 to 13% range rather than the 12 to 14%) and adding 0.20% aluminum. Fortunately, within the last few years the steel industry has discovered how to drive the carbon content of stainless alloys down to levels formerly thought impracticable.

Varying amounts of aluminum up to 0.40% have no discernible effect on the hardness of Type 405 alloys quenched from 1900 to 2000° F. Table IV gives data obtained from quenching sheets $\frac{5}{64}$ to $\frac{7}{64}$-in. thick. The last line is for an aluminum-free alloy having 0.077% nitrogen. While nitrogen is an addition recommended by some metallurgists, we have not found any beneficial effect in the alloys containing 11 to 13% chromium.

Furnace Cooling — A further effect of aluminum in the Type 405 analysis is not shown by these curves but is illustrated in Fig. 3. When 0.12%

0.05 C, 12.28 Cr, 0.21 Al,
0.31 Mn, 0.33 Si, 0.11 Ni

0.12 C, 12.58 Cr,
0.43 Ni



0.06 C, 12.40 Cr,
0.40 Mn, 0.49 Si, 0.09 Ni

Fig. 1 — Showing Advantage of Low Carbon Plus Aluminum in Suppressing Hardenability of 12% Chromium-Irons

carbon Type 410 alloy is heated to 2200° F. and furnace cooled, its hardness increases to 350 Brinell (Curve No. 1). This was also true of Type 410 with 0.46% molybdenum when cooled from 2100° F. (Curve No. 4). With the addition of 0.10 to 0.40% aluminum, the 11 to 13% Cr alloy does not increase in hardness above 150 Brinell when furnace cooled from any temperature up to 2200° F. (Curves No. 3 and 5, Fig. 3, p. 95.)

As further evidence that Type 405 chromium-iron is not embrittled with high temperature heating we took $\frac{7}{64}$-in. sheets analyzing 0.07% C, 13.44% Cr, 0.28% Ni and 0.27% Al, and heated as shown in the schedule below, then made a notch with a hacksaw to a depth of $\frac{3}{64}$ in. and bent the samples:

Treatment	Angle of Bend; Notched
None; as mill annealed	146°
Heated to 2200° F.; air cooled	145°
Above; reheated to 1200° F.	123°
Reheated to 1450° F.	123°
Reheated to 1650° F.	125°

Lastly, a Type 405 alloy was oil hardened from 1800° F. and drawn and tested at various temperatures ranging from 400 to 1400° F. Hardness and Charpy keyhole notched-bar tests were made; Fig. 4 gives no indication of a notch-brittle range in these tests.

The addition of aluminum to the low-carbon, 11 to 13% Cr appears to accomplish three things in Type 405 alloys:

1. Restrict the gamma loop so a properly conditioned alloy is almost entirely ferritic at all temperatures. See Table V, p. 96. (Mr. Newell estimates that 0.10% aluminum has the same effect in this respect as an extra 1.00% chromium.)

2. Raise the temperature at which transformation (if any) begins.

3. After overheating, the alloy is all alpha (ferritic).

The studies outlined above indicate that low-carbon Type 405 would be a good alloy as far as its inertness to welding and other heating operations during fabrication is concerned. Later experiences convinced us that additions of molybdenum are not harmful but that columbium and titanium are positively harmful. These facts will be discussed later. The chemistry now favored for Modified Type 405 for refinery service is shown at top the next column.

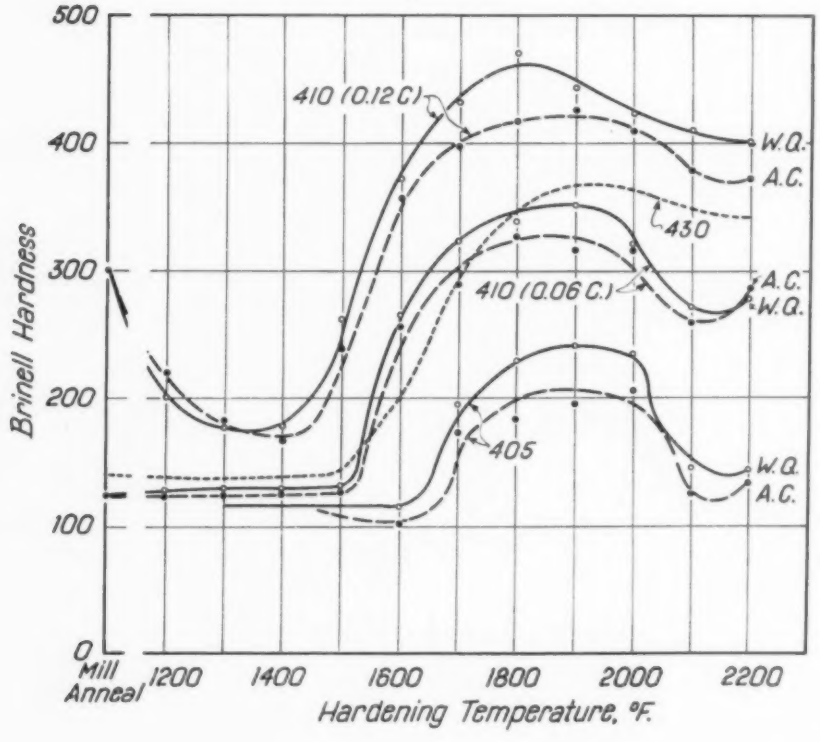


Fig. 2 — Hardness of Types 430, 410 and 405 After Water Quenching or Air Cooling From Various Temperatures

	Type 430	410 (0.12 C)	410 (0.06 C)	405
C	0.04	0.12	0.06	0.05
Cr	16.86	12.58	12.40	12.28
Ni		0.43	0.09	0.11
Al				0.21

Preferred Chemical Specifications

	Chromium-Aluminum	Chromium-Molybdenum-Aluminum
C	0.08% max.	0.08% max.
Mn	0.20 to 0.50%	0.20 to 0.50%
P	0.030% max.	0.030% max.
S	0.030% max.	0.030% max.
Cr	11.00 to 13.00%	11.00 to 13.00%
Si	0.50% max.	0.50% max.
Ni	0.30% max.	0.30% max.
Al	0.20 to 0.30%	0.20 to 0.30%
Cu	0.10% max.	0.10% max.
Ti	0.02% max.	0.02% max.
Cb	0.02% max.	0.02% max.
Mo	0.05% max.	0.40 to 0.60%

Long-Time Stability

While stability under operating conditions can be determined only in the performance of operating equipment, certain laboratory investigations indicated that Types 410 and 405 would be free from high temperature, long-time embrittlement. One method would be to hold samples steadily in a hot laboratory furnace for long periods of time, and find out whether their hardness was increased thereby, when tested at room temperature — the assumption being that a gain in hardness would indicate a corresponding degree of embrittlement, an assumption not altogether justified, especially if "brittleness" is defined as a low value of energy absorbed in notched-bar impact test. For example in Table VI three samples are shown with B-96 hardness; their respective Charpy values are 32.2, 3.5, and 44.5 ft-lb. The last one is a Type 405 alloy and certainly is not brittle — it *gained* impact value during exposure.

Fig. 5 shows such age-hardening curves for various temperatures for Type 430 (known to embrittle), and at 880° F. — a temperature within the dangerous range — for Type 410 and two samples of Type 405. The latter alloy with 13.44% Cr shows very slight age-hardening tendencies, and it was for this reason that we favored the Modified Type 405 alloy with 13% Cr as a maximum. It is not shown on this graph, but 9200-hr. exposure of this alloy with 13.44% Cr at 840 to 890° F. increased

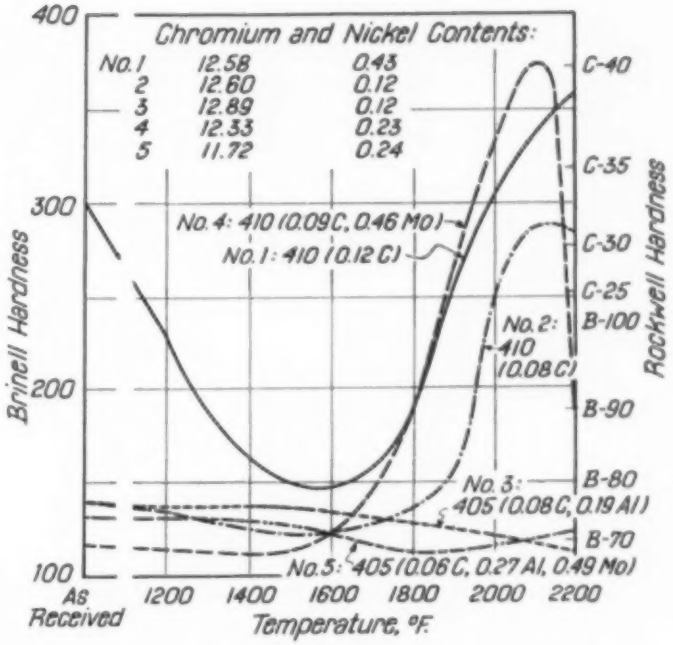

Chromium and Nickel Contents:
No. 1 12.58 0.43
2 12.60 0.12
3 12.89 0.12
4 12.33 0.23
5 11.72 0.24
No. 4: 410 (0.09 C, 0.46 Mo)
No. 1: 410 (0.12 C)
No. 2: 410 (0.08 C)
No. 3: 405 (0.08 C, 0.19 Al)
No. 5: 405 (0.06 C, 0.27 Al, 0.49 Mo)
Brinell Hardness
Rockwell Hardness
Temperature, °F.
As Received

Fig. 3 — Hardness of Types 410 and 405, Furnace Cooled From Various Temperatures

Table IV — Effect of Aluminum on Hardenability of Type 405

Analysis			Heating Temperature	Maximum Brinell		
C	Cr	Al		Air Cooled	Water Quenched	After 1200° F. Stress Anneal
0.05	12.67	0.13	2000° F.	267	275	216
0.04	12.91	0.15	1900	195	236	180
0.08	12.89	0.20	2000	285	335	210
0.07	13.44	0.27	1900	250	270	200
0.06	12.45	0.36	1900	222	275	188
0.06	12.39	Nil*	1800	388	400	230

*0.077 nitrogen.

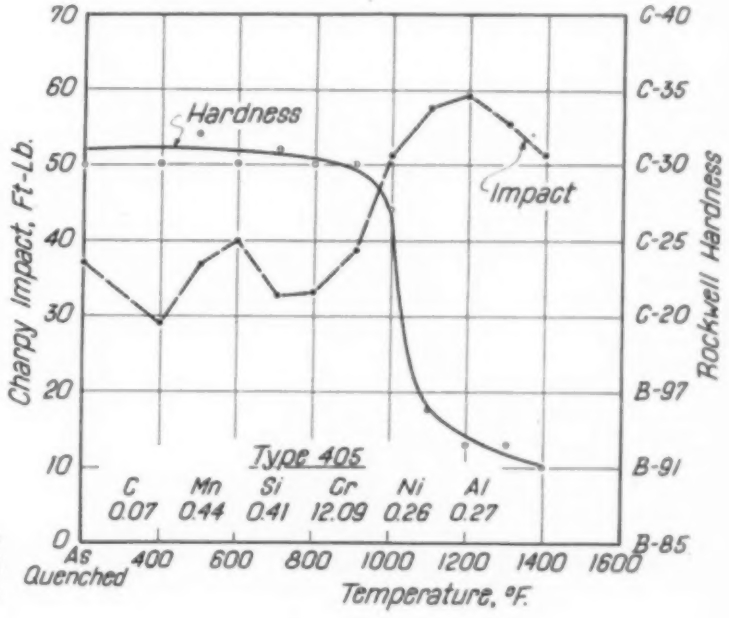


Fig. 4 — Hardness and Charpy Keyhole Notched-Bar Tests on Quenched and Drawn Type 405 (Samples Tested at Temperature Indicated)

Table V — Effect of 0.20% Aluminum on the Microstructure of 11 to 13% Chromium-Iron

	Type 410	Type 405	Type 405
Analysis			
Carbon	0.07%	0.07%	0.08%
Manganese	0.34	0.37	0.37
Silicon	0.40	0.43	0.42
Nickel	0.17	0.12	0.14
Chromium	13.14	12.32	12.91
Aluminum	—	0.22	0.19
Heating temperature			
1500° F.*	100% alpha	100% alpha	100% alpha
1600	60 alpha	100 alpha	100 alpha
1700	10 alpha	100 alpha	95 alpha
1800	100 gamma	20 alpha	60 alpha
1900	95 gamma	30 alpha	60 alpha
2000	90 gamma	30 alpha	60 alpha
2100	80 gamma	50 alpha	65 alpha
2200	60 gamma	75 alpha	80 alpha
2300	60 gamma	85 alpha	100 alpha
2400	40 gamma	95 alpha	100 alpha
Heated to 2400° F. and then reheated to			
1600° F.	60% alpha	100% alpha	100% alpha
1700	10 alpha	95 alpha	95 alpha
1800	100 gamma	80 alpha	95 alpha
1900	95 gamma	75 alpha	95 alpha
2000	90 gamma	75 alpha	100 alpha
2100	80 gamma	95 alpha	100 alpha
2200	60 gamma	100 alpha	100 alpha

*Transformation begins at 1525° F. for Type 410.

hardness from B-72 original to B-86 at the end; however, there was no marked embrittlement as judged by notched-bend tests.

An alloy very similar to the 12.09% Cr Type 405 of Fig. 5, but having 0.064% C, 0.31% Mn, 11.99% Cr, 0.12% Ni, 0.38% Si, 0.60% Mo and 0.27% Al, was heated separately at 700, 800, 900, 950 and 1000° F. for 2000 hr. The maximum change in Rockwell B from start to finish was two points. Plain bend test and notched-bend tests were made at room temperature after each heating and showed no impairment of the ductility.

Table VI exhibits a comprehensive series of tests on aging embrittlement, made by one of our steel suppliers, at our request. It gives complete physicals before and after an aging treatment at 800° F. for 1050 hr. on six analyses. There is no embrittling effect shown with 12% Cr alloys containing up to 0.40% aluminum.

A similar conclusion can be drawn from a test in the A. O. Smith laboratory of an alloy containing 0.06% C, 12.45% Cr, 0.35% Ni and 0.36% Al.* Hardness tests made at room temperature after 1000 hr. at 800° F. showed a gain in hardness of 1.5 Rockwell B-scale units, and no change after 1000 hr. at 900° F. Charpy keyhole notch test absorbed 57.5 ft-lb. at room temperature, as received; 60.9 and 54.9 after 1000 hr. at 800° F., and 52.5 and 54.9 after 1000 hr. at 900° F. All specimens bent 180° flat without fracture. Tensile data on 0.357-in. round specimens of this test, as received and heat treated in various ways, are shown in Table VII.

Investigation of Reported Embrittlement of Types 410 and 405

The results of these tests, but more especially the satisfactory service in hundreds of lined vessels in petroleum refinery service, are evidence that the Modified Types 410 and 405 alloys, *when properly made and installed,* are permanent. The present author has learned of only six "incidents" where trouble was encountered. Brief case histories of all of these will now be presented and a diagnosis given wherever possible.

Case A; Excess Chromium — Some refinery engineers have preferred the 12 to 14% range of chromium in the Type 410, presumably for the added corrosion resistance of the extra 1% chro-

*Other elements: 0.31% Mn, 0.31% Si, 0.018% P, 0.015% S, 0.05% Cu, 0.02% Mo, nil Cb and Ti.

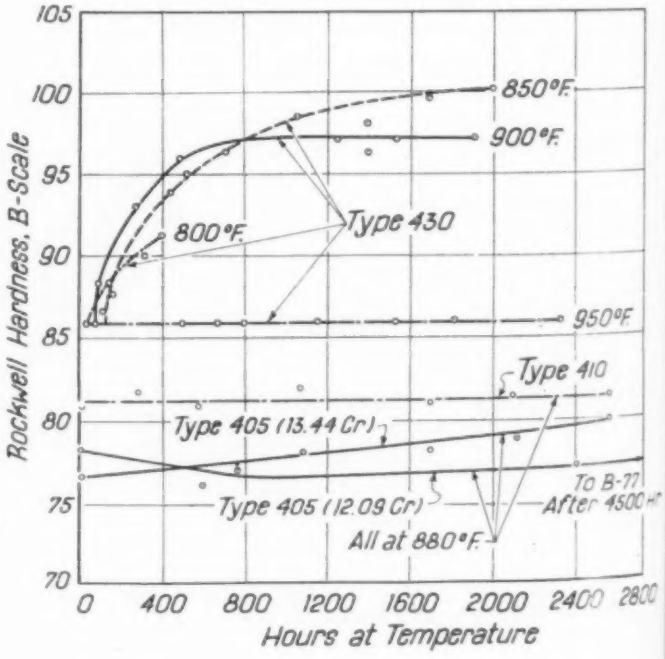
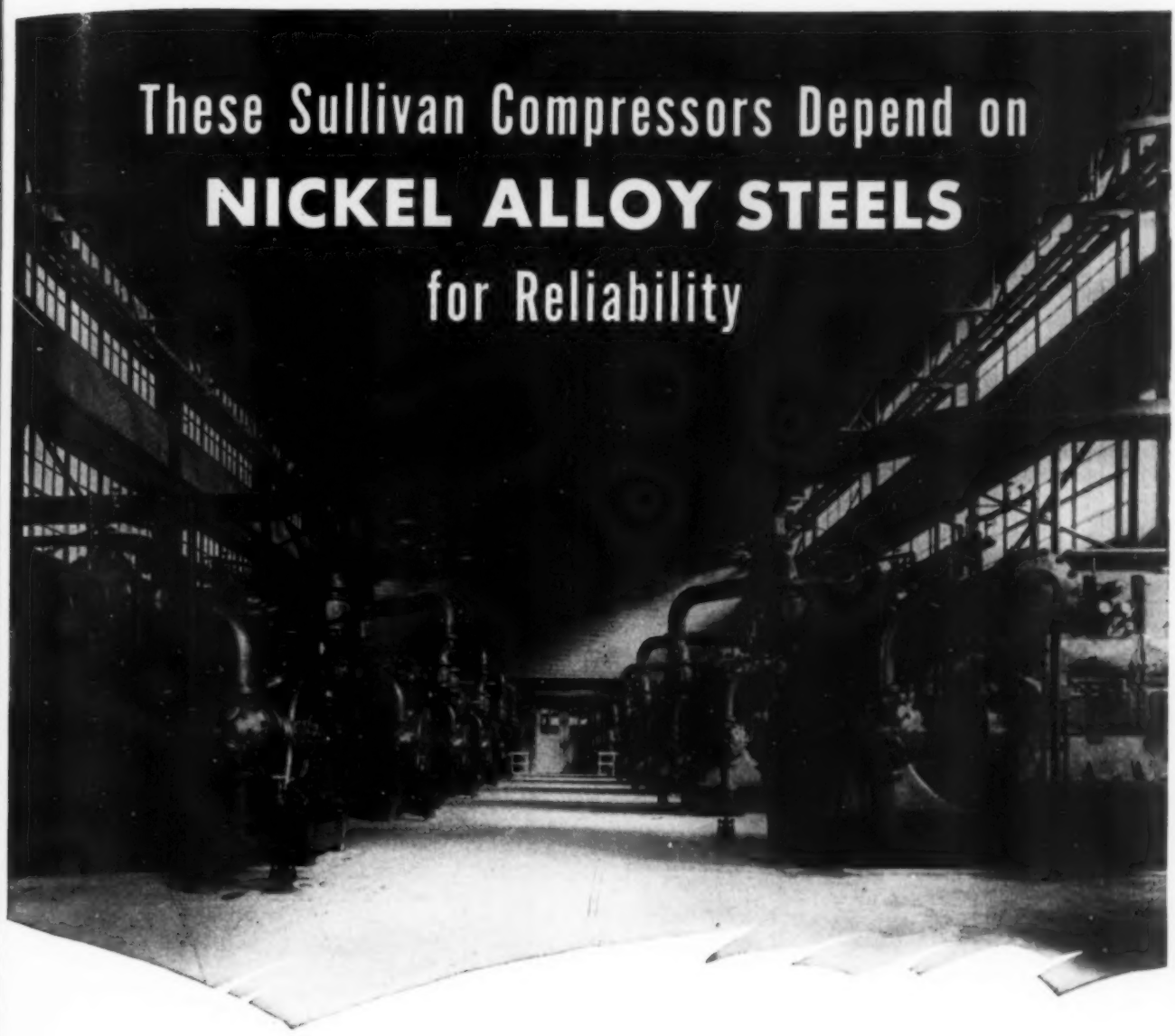


Fig. 5 — Hardness of Types 430, 410 and 405 After Long Stay at Elevated Temperatures

	Type 430	410	405 (13.44 Cr)	405 (12.09 Cr)
C	0.08	0.12	0.07	0.07
Cr	16.96	12.58	13.44	12.09
Ni	0.22	0.43	0.28	0.26
Al			0.27	0.27



These compressors, built by the Sullivan Division of Joy Manufacturing Company, are a good example of the way Nickel alloy steels help make equipment longer-lasting and more dependable.

Crankshafts in these units are of large diameter, and accordingly, a Nickel-chromium-molybdenum steel, Type 4340, is used to secure good depth hardening. This steel makes possible heat treated forgings that provide ample strength, good ductility and ready machinability.

Cross head pins and other stressed parts are produced in a case hardening Nickel-molybdenum steel, Type 4615. This steel responds readily with minimum distortion to simple quenching treatments, and affords a wear resistant, non-spalling surface supported by a tough core that enables the part to resist shocks and overloads.

The excellent mechanical and fabricating properties of Nickel alloy steels provide a practical answer to problems of low-cost, trouble-free operation of equipment.

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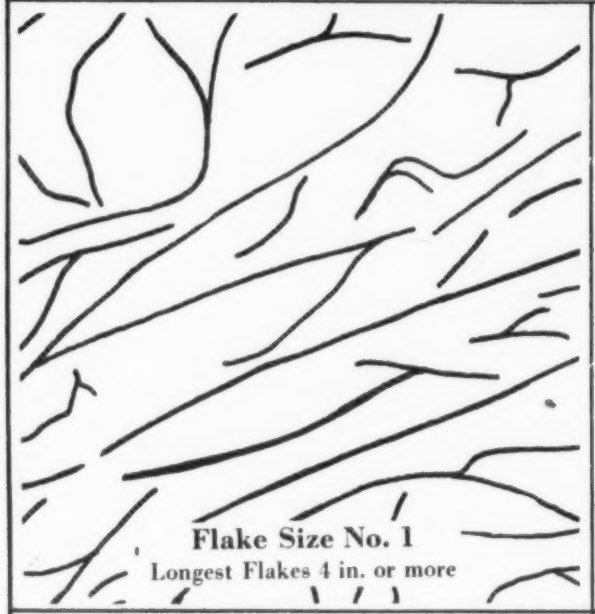
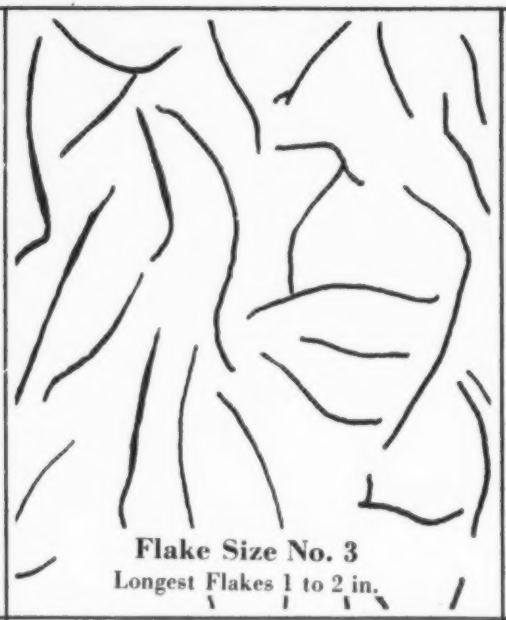
Graphite Flake Size in Gray Cast Iron

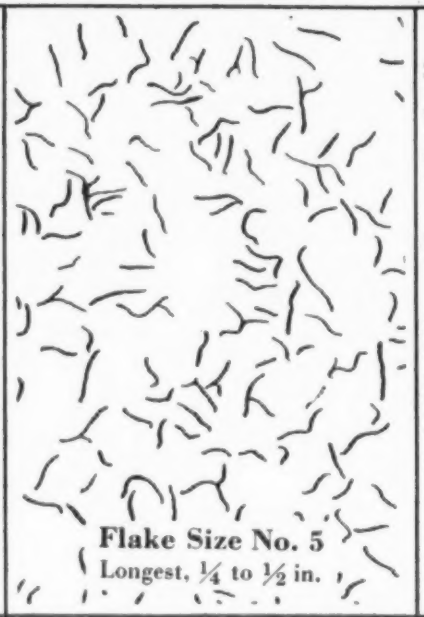
Recommended Jointly by American Foundrymen's Association and American Society for Testing Materials 100×



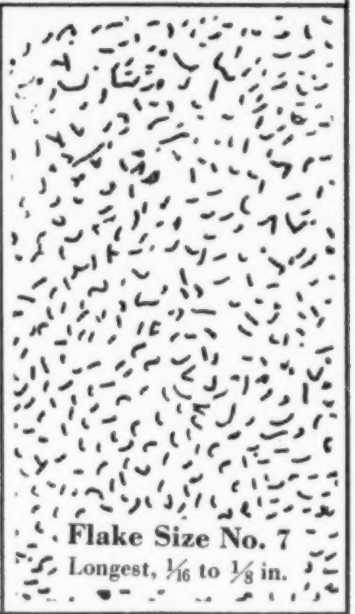
Flake Size No. 1
Longest Flakes 4 in. or more



Flake Size No. 3
Longest Flakes 1 to 2 in.

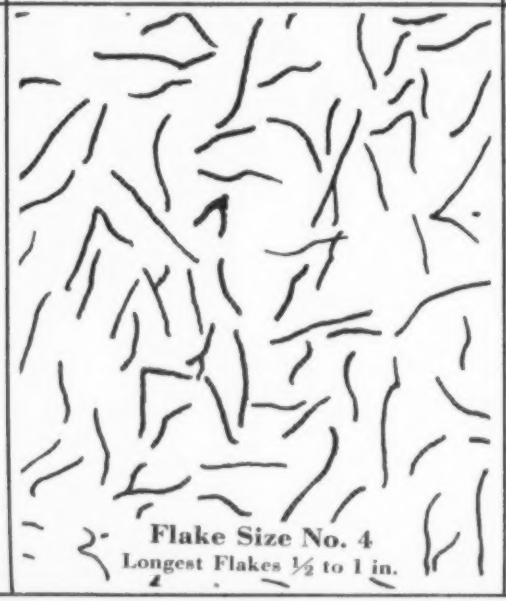


Flake Size No. 5
Longest, ¼ to ½ in.

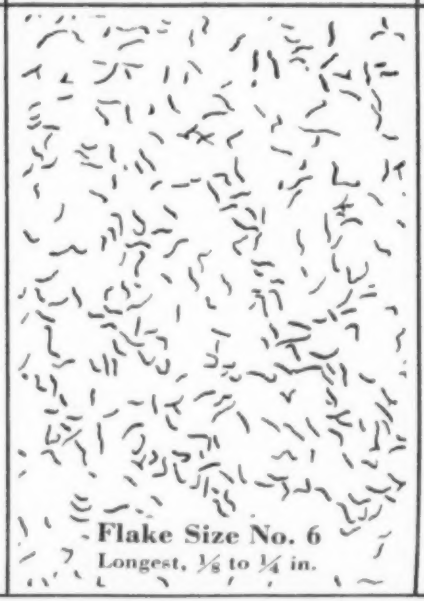


Flake Size No. 7
Longest, 1/16 to ⅛ in.

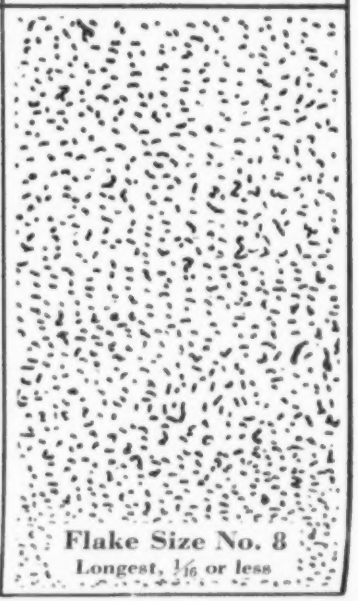
Flake Size No. 2
Longest Flakes 2 to 4 in.



Flake Size No. 4
Longest Flakes ½ to 1 in.



Flake Size No. 6
Longest, ⅛ to ¼ in.



Flake Size No. 8
Longest, 1/16 or less

Table VI — Physical Tests on Straight Chromium Alloys After 1050 Hr. Exposure at 800° F.

Chemical Analysis				Yield Point	Ultimate Strength	Elongation in 2 In.	Reduction of Area	Rockwell Hardness	Keyhole Charpy
C	Cr	Ni	Al						
0.15*	16.7	0.23	0.03	75,600	117,200	25.5	42.3	B- 96	32.2
		After exposure		102,200	136,000	26.0	37.3	B-101	10.7
		Per cent change		+26	+13.8	+1.9	−11.7	+5.5	−66.8
0.04*	17.0	0.24	0.018	66,150	98,050	30.5	49.0	B- 84	48.8
		After exposure		105,000	124,100	25.2	41.5	B- 96	3.5
		Per cent change		+37	+20.1	−17.2	−15.4	+15.3	−93.3
0.12	11.6	0.14	0.039	88,200	118,000	23.75	43.3	B- 94.5	42
		After exposure		94,600	121,950	23.75	40.5	B- 95.0	37
		Per cent change		+7.2	+3.35	....	−6.58	+0.53	−11.9
0.05	11.7	0.15	0.041	64,700	98,266	30.3	48.5	B- 79	48
		After exposure		58,250	96,150	34.2	48.8	B- 81	43
		Per cent change		−9.97	−2.16	+11.5	+0.6	+2.5	−12
0.07	11.6	0.06	0.21	60,500	90,750	33.0	54.0	B- 81.8	51.2
		After exposure		56,100	92,650	33.5	49.9	B- 81.7	54
		Per cent change		−7.28	+2.0	+1.5	−7.6	....	+5.1
0.06	12.0	0.06	0.40	54,500	86,400	34.2	46.7	B- 95.8	44.5
		After exposure		58,000	87,900	33.5	50.5	B- 95.2	47.0
		Per cent change		+6.03	+1.79	−0.22	+7.6	....	+5.3

*An interesting footnote to the *cause* of 885° embrittlement might be written about the tests on these two Type 430 alloys. More embrittlement occurred in the alloy with 0.04% carbon than the one with 0.15%.

Table VII — Tensile Tests on Heat Treated Type 405 Bars

	As Received	Cooled in Air Blast From 1800° F.		
		Not Reheated	Reheated 1100° F.	Reheated 1200° F.
Yield (0.5% offset)	46,000	81,150	59,600	65,000
Ultimate	66,650	109,500	82,500	84,200
Elongation in 2 in.	37.9	23.6	28.6	28.6
Reduction of area	66	41	60	42
Rockwell	B-76	B-96.5	B-88.5	B-88

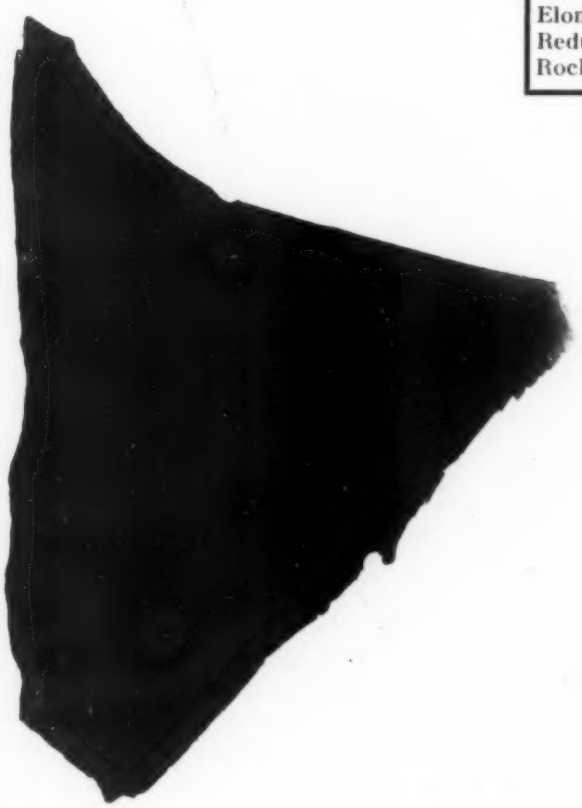


Fig. 6 — Specimen of Lining as Received From Phillips Petroleum Co. Brittle fracture in Type 405 at left is outlined; Type 410 is at right of weld. About half natural size

mium. I have heard of one case where it was reported that Type 410 alloy with 13.65% Cr was embrittled at 800 to 900° F. after two years' exposure. This experience and laboratory aging tests on several heats of 405 analysis with chromium 13 to 14% led A. O. Smith Corp. to a preference for 11 to 13% chromium with 0.08% carbon max.

Case B; Excess Cold Work and Chromium Suspected — Mr. Newell, in his article in *Metal Progress* for April 1947, cited an illustration of "embrittlement of Type 405 with aluminum" which was originally investigated by the Phillips Petroleum Co. Type 410 and 405 lining was used in strip form to line an existing tower (a field job rather than a fabricator's), and the vessel was in service at a temperature averaging 735° F. with fluctuations as high as 820° F. over a period of five years. On inspection, some cracks appeared only in the Type 405 lining adjacent to field weld seams; such metal was stated to test B-95 Rockwell and to be brittle toward bending. Material on one side of the weld was not brittle and was found to be of

Fig. 7 — Type 405 From Phillips Petroleum Co. Transverse section (50 ×) showing transcrystalline rupture. Rolled surface showed much evidence of light intergranular attack

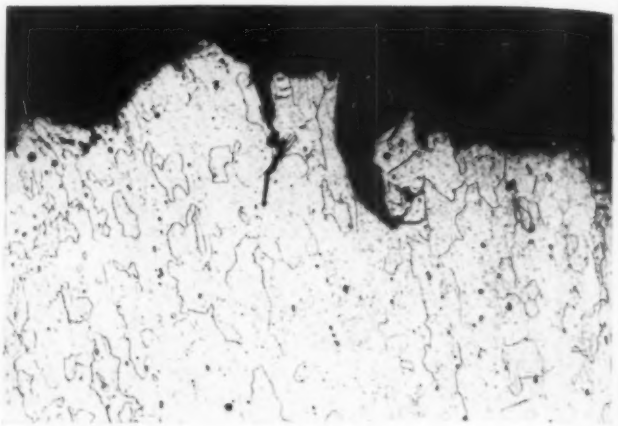
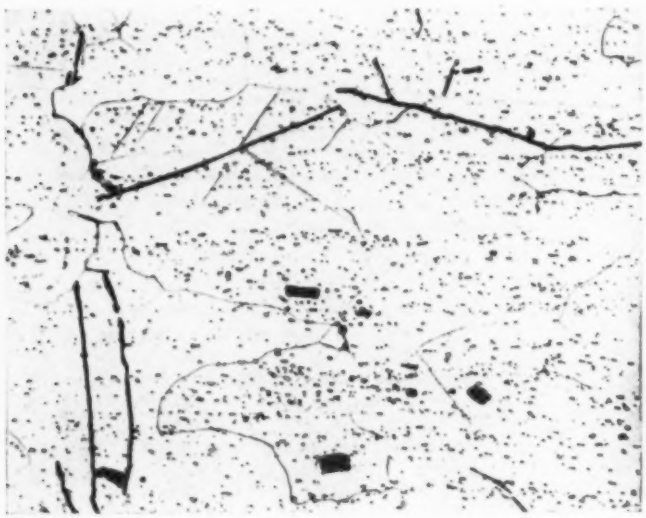


Fig. 8 — Same as Fig. 7; Sample as Received. 400 ×. The metal was heated in service 5 years at about 735° F. Finely scattered chromium-iron carbides and a small amount of pinkish titanium carbide in large grains of chromium ferrite. Transverse ruptures with a few Neumann bands originating therefrom indicate shock loading. Rectangular inclusions are chromite and hercynite



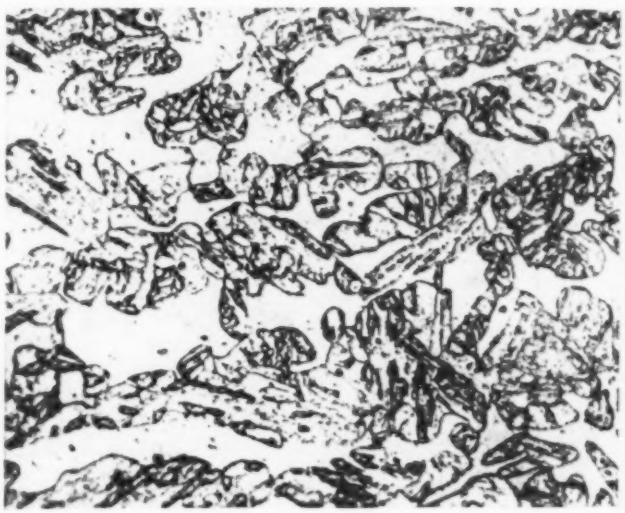


Fig. 9 — Type 405 From Phillips Petroleum Co. After Heating 5 Min. at 2000° F., Water Quenching, Reheating to 1450° F., and Air Cooling. 400 ×. Structure: Tempered martensite in Cr-Fe ferrite

Type 410. The analysis of both materials was reported as:

	Cr	C	Al	Hardness
Ductile	12.94%	0.07%	None	B-88
Brittle	13.18	0.08	0.18%	B-95

The writer secured a triangular shaped specimen measuring approximately 6 in. on a side for spectrographic, wet chemical and microscopic analyses from M. E. Holmberg of Phillips' engineering department. Figure 6 shows the as-received specimen, which was covered with a hard, thin, black deposit on both surfaces, outside and inside. Two sides of the Type 405 alloy showed a brittle fracture and a sawcut; the other edge had been gouged with a chipping tool. Figure 7 indicates that the path of fracture in the Type 405 was transgranular, and Fig. 8 shows transverse cracks in the chromium ferrite grains with Neumann bands (shock lines) back of the fractured surface. The hardness of this sample as we received it was B-88 to 96 measured on the surface of the alloys in contact with the carbon steel, and B-98 to 101 measured on cross sections; after heating to 2000° F. and water quenching the Type 405 alloy was C-25 to 28; after heating to 2000° F., water quenching, and then reheating to 1800° F. and air cooling it was C-22. A photomicrograph, Fig. 9, shows that this alloy under investigation reacts to hardening similarly to regular Type 405; it is usual to find that Type 405 does not harden below C-15 nor above C-33 (Brinell 200 and 300 respectively).

See Fig. 10 for a more complete study of the microstructure of the Type 405 and 410 alloys in the sample under investigation. The apparent difference is indicated; namely, the Type 410 alloy (Fig. 10*a*) contains elongated grains suggesting low finishing temperature in rolling or possibly some cold rolled finish. The Type 405 exhibits moderate sized equiaxed chromium ferrite (Fig. 10*b*). Both alloys exhibit finely precipitated chromium carbides; however, no titanium carbo-nitrides of the characteristic cubical shape were found in either of these alloys.

Figure 10*c*, at somewhat higher magnification, is a duplicate of Fig. 10*a*; it shows precipitation of carbides along strain lines, proving that the alloy was cold worked prior to service exposure. A broadening of the grain boundaries was observed (as already noted by Mr. Newell in his April *Metal Progress* article). Figures 10*d* and 10*e* of Types 405 and 410 respectively show the grain size after a laboratory furnace anneal at 1450° F. which reduced the hardness to B-75 to 78 on Type 405 and B-67 to 68 on Type 410. This temperature is considerably below the transformation temperature normally found for annealed alloys of these types. Figure 10*c* shows an enlarged grain size as compared to the as-received Type 410 sample, proving that "cold work" was responsible for the lower recrystallizing temperature.

The size of this piece permitted several ½-in. wide test pieces in both alloys. Bend tests were made in two directions — parallel and perpendicular to the field fillet weld. The plain bend specimens were tested in a jig bending fixture, which for $\frac{7}{64}$-in. thick sheet produces 50 to 55% elongation in the outer fibers when bent to 180°. The material from Phillips was $\frac{5}{64}$-in. gage.

Figure 11, page 100, shows the plain jig bend tests of the as-received alloys with the service side of the lining in tension during bending. The Type 405 bends 180°; Fig. 12 shows small surface cracks after bending. This specimen was cut to include part of the original brittle-appearing fracture in evidence on the as-received sample, and it was located at the point of maximum bend. These tests apparently do not duplicate the reported brittle fracture. The Type 410 alloy bends 90° and cracked as shown in Fig. 12.

A similar test piece bent 180° in both materials after removing the service surface which contained intergranular oxide penetrators. The improvement in ductility for the Type 410 is attributed to the removal of intergranular oxidation or corrosion.

Plain jig bends of the as-received Type 405 alloy were also made in a direction parallel to the weld (or 90° to the bending shown in Fig. 11), with service side of the lining in tension. Two bend tests of 180° again proved the ductility of the Type 405 alloy. Notched-bend tests were also made of both alloys, the notch cut with a hacksaw to a

Type 410

10a — As received; B-100 to 101
10c — Like 10a; 2000 ×
10e — Annealed 30 min. at 1450° F.; B-67/68

Type 405

10b — As received; B-98 to 100
10d — Annealed 30 min. at 1450° F.; B-75/78

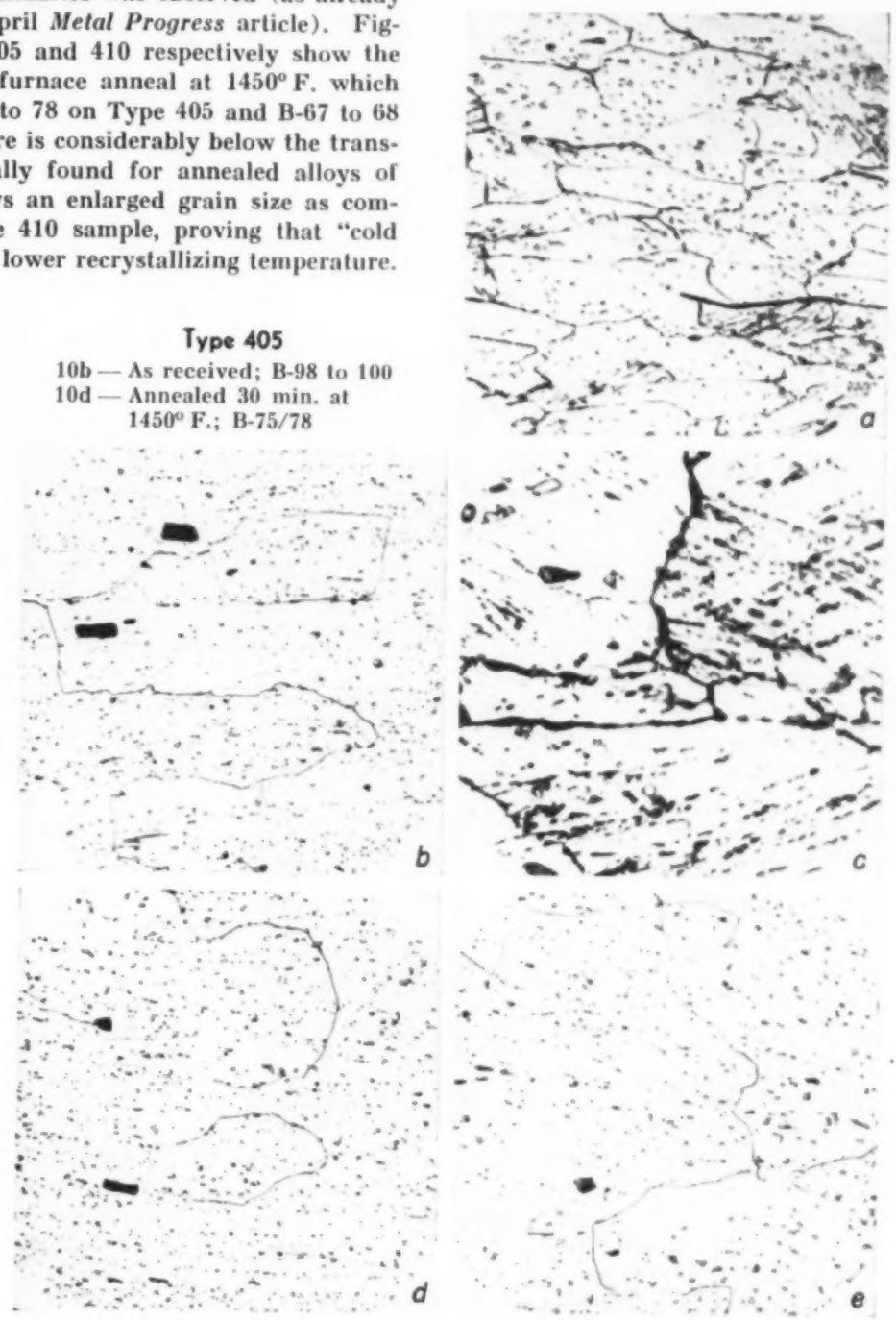


Fig. 10 — Microstructure of the Two Alloys of Fig. 6, Etched With Aqua Regia Plus Cupric Chloride. All 500 × except 10c which is 2000 ×

Fig. 12a — Tension Side of 90° Bend in 410. 2 ×

Fig. 11 — Bend Test Made With Surface in Service in Tension. Type 410 at top cracked on 90° bend; Type 405 at bottom cracked at 180° bend. 2 ×

depth of $\frac{1}{64}$ to $\frac{1}{32}$ in. Notch bending of both alloys was comparable, being about 90° with the $\frac{1}{64}$-in. deep notch and about 55° with the $\frac{1}{32}$-in. deep notch. When these results are compared with tests on the same alloys after annealing at 1000° F. for 3 hr., we obtained a notched-bend test of almost 90° on the Type 410 and 110° on the Type 405.

After the 1000° F. anneal the hardness decreased from a maximum of B-95 to a figure of B-86 for the Type 405 strip and from a maximum of B-98 to a figure of B-92 for Type 410. A stress anneal at 1200° F. for 2 hr. (air cool) resulted in surface hardness readings of B-81 to 83 for the Type 410. This emphasizes the desirability of stress relieving the Type 410 lining after field welding.

Finally, a complete spectrographic analysis and check wet analyses were made by three independent laboratories. Milled chips for the wet analyses were from the full linear thickness after pickling and passivating in nitric acid to remove all oxides. Results are shown in Table VIII.

Fig. 12b — Tension Side of 180° Bend in 405. 2 ×

Our study of the reported embrittlement would be summarized as follows:

1. The Type 405 alloy is found to be as ductile as the Type 410 alloy by bend tests.

2. The hardness of both alloys is the same after the five years' service.

3. The notched-bend test, hardness, and microstructure of both alloys indicate age hardening but no brittle tendencies at room temperature.

4. The hardness increase for the Type 405 alloy is attributed to its chromium content, which is over 13%. The titanium content is not sufficient to cause embrittlement.

5. The hardness increase for Type 410 is attributed to the effect of cold work on the original alloy. Microstructural evidence indicates that prior cold work, usually associated with acceleration of aging, has been responsible.

From information from various sources on annealed Type 410 stainless iron, it would appear that chromium content is critical when it is above 13% as regards susceptibility to 885° F. embrittlement. The lower carbon alloys (0.06% and less, which are favored for lower hardenability) can be *more* critical because less chromium is combined as a stable carbide. Thus it would appear logical to reduce chromium below 13% when carbon is below 0.06%, otherwise the chromium enriches the ferrite with liability for 885° embrittlement. For example, the low-carbon Type 430 alloy listed in Table VI indicates a greater degree of aging than the 0.15% carbon alloy.

It is perhaps worthy of re-emphasis that hardness is not always a criterion of brittleness. Supplementary observations — visual cracks, short bends, low notched-bar tests, transcrystalline rupture — must establish the true facts.

Case C; Excess Titanium — In 1943 we found embrittlement in ¾-in. bar stock used for hooks in a coke chamber three years with temperature of 880° F. max. The alloy was bought as Type 405 with reported analysis as shown; the analysis of the brittle hooks also is listed.

	C	Mn	Si	Cr	Al
Stock	0.05%	0.48%	0.47%	13.23%	0.28%
Hooks	0.05	0.46	0.44	12.96	0.28

Other elements were 0.018% S, 0.035% P, 0.15%

Ni, 0.01% Mo, 0.04 to 0.12% Ti, 0.07% Cu, <0.01% Sn. Tests on original material (unused) were:

	Hardness	Keyhole Charpy
Annealed at 1450° F.	B-75	42.0 ft-lb.
After 4470 hr. at 880° F. in laboratory furnace:	83.5	2.9 to 2.4
Maximum hardness on heating to 2100° F. and water quenching:	95	

After three years' exposure to coking service, the metal was B-96 hard and Charpy tests gave only 1.7 to 1.8 ft-lb. However, heating this brittle hook material for 3 hr. at 1000° F. removed all notch sensitivity and reduced hardness to B-82, but the embrittled condition returned after 1000 hr. at 880 to 900° F. with a hardness increase to B-89.

The cause of this trouble was very definitely the titanium in the alloy, unknown when purchased and put into service. This alloy with titanium could not be grain refined after coarsening by any of the heat treatments tried, and the alloy was not hardened to the extent of regular Type 405 by water quenching from temperatures of 1400 to 2100° F., its maximum, as noted, being B-95 (approximately Brinell 210) — about the *minimum* for normal Type 405.

Case D; Columbium Suspected — Five different alloys of Type 410 and 405 as shown in Table IX were exposed 9198 hr. in an ammonia converter operating at 840 to 890° F. and 1600 to 2000-psi. pressure. They acquired a nitrided case, but this was machined off before the specimens were made and tested. Little indication of embrittlement existed in the tensile properties or the change in hardness, yet one alloy exhibited brittleness in the notched-bend test as well as greater hardness and tensile increase, and that was Type 410 with 0.53% Mo and 0.47% Cb. From this it appears that columbium acts like titanium. We believe that both should be limited to 0.02% in Modified Types 410 or 405.

Type 405 with about 0.6% molybdenum performed satisfactorily after this test, although the low notched-bend test is ascribed to banding in the alloy. However, in another comparison made with Type 405 alloy containing no detectable titanium or columbium, the Type 405-Mo alloy notch-bent 100° after exposure for 5300 hr. to 840 to 890° F. Here again the sample split longitudinally due to banded microstructure. No evidence of embrittlement existed when tensile values and hardness were compared, before and after exposure.

The notched-bend test was used in this series because the specimens were ⅛ to ¼ in. thick, and we have found that a slow bend on notched test pieces is a good criterion of brittleness.

Case E; Type 410 High in Cr — A sample of field plug-welded lining 0.080 in. thick was examined after 18 months' service at operating temperature of 750 to 825° F. The sample represented a bulge in the lining which was flattened when it was cold; in flattening, the lining cracked and a small section was cut out for examination.

This lining was ordered as Type 410 but analyzed 0.08% C, 14.75% Cr and 0.56% Mo. This chromium was much beyond the safe limit.

The embrittled lining tested Rockwell B-98 to 99 and was very sensitive to notches and scratches when bent. We succeeded in bending a sample 180° cold after polishing the tension surface of the bend. As it was removed from service, the material exhibited extreme brittleness in the plain bend test.

Heating the sample one hour at 950° F. reduced the hardness to B-95. Heating at 850° F. did not change the hardness from B-99. Heating

Table VIII — Analyses of Plates From Phillips Petroleum Co.

	Type 405					Type 410			
	Spectroscopic *(a)*		Wet Analysis			Spectroscopic *(a)*		Wet Analysis	
	Back Surface	Service Surface	*(b)*	*(c)*	*(d)*	Back Surface	Service Surface	*(b)*	*(d)*
C	—	—	0.078	0.08	0.08	—	—	0.056	0.08
Mn	0.47%	0.51%	0.43			0.42%	0.48%	0.41	
Si	0.49	0.52				0.25	0.33		
Cr	13.10	13.40	13.10	13.18	13.14	12.80	12.90	12.80	12.97
Ni	0.13/0.18	0.13/0.18			0.05	0.13/0.18	0.13/0.18		0.22
Al	0.22	0.225	0.13	0.22	0.26	<0.02	<0.02	0.006	n.d.
Cu	0.07	0.07				0.06	0.06		
Mo	<0.01	<0.01				<0.01	<0.01		
Ti	<0.02	<0.02	Nil	0.009		Nil	Nil	Nil	
Pb	<0.01	<0.01				0.01	0.01		
Sn	<0.01	<0.01				Nil	Nil		
Mg	Trace	Trace				Nil	Nil		
W	Nil	Nil				Nil	Nil		
V	<0.01	<0.01				<0.01	<0.01		

(a) By W. Poehlman, A. O. Smith Spectrographic Research Laboratory.
(b) Reported by Globe Steel Tubes Co. Research Laboratory.
(c) Reported by Carnegie-Illinois Steel Corp., South Works Laboratory.
(d) By A. O. Smith's Production Laboratory.

the sample to 1750° F. and cooling in air blast resulted in a hardness of B-99, but the alloy was then ductile.

Case F; Stress Corrosion — In 1940 we examined a sample of Type 405 plug-welded field lining to determine the suitability of this material under service conditions. An analysis yielded 0.06% C, 12.16% Cr, 0.07% Ni and 0.24% Al, which meets the requirements for Type 405. Operating temperature was probably 850 to 900° F. over a period of about two years.

Micro-examination in an area showing surface checking revealed corrosion penetration to a depth of 0.005 in. on either the outer surface exposed to the service conditions or on the under surface formerly in contact with the carbon steel. Many of the corrosion cracks had penetrated along the grain boundaries. This suggested that stress was also involved in the operation.

Due to the fact that there were leaks in the lining and coke was depositing between it and the steel vessel, forcing the lining away from the carbon steel shell, tensile stresses were set up in the service surface of the lining material, and under the corrosive conditions of service the attack was preferential rather than general. There was evidence from the microspecimens that corrosion fatigue had caused some of the surface checking, particularly since some of the cracks were of a transgranular nature.

That the lining as a whole was not brittle was attested by the fact that several bend tests went 180° without failure. The outer fibers of the bend specimens were slightly cracked due to the preferential corrosion attack in the stressed areas, but the body of the sheet was sound. Its hardness was only B-69. Heating to 1700° F. and air cooling resulted in a hardness of B-75.

Résumé

These six recorded instances are certainly not sufficient adverse data to condemn the use of Modified Type 405 with 13% max. Cr, 0.08% max. C, and 0.02% max. Ti or Cb for refinery service at 700 to 1000° F. Since 1938 experience of the A. O. Smith Corp. with Modified Type 405 of the composition specified in over 100 pressure vessels, and working in the embrittling temperature range, has not produced *one single hardened brittle lining* when the analysis has been within the proper specification.

The experience to date suggests that A.I.S.I. Type 405 or 410 with 0.08% C max. should be modified from 11.5 to 13.5% Cr to 11.0 to 13.0% Cr, to avoid possible embrittlement in service.

It follows that if carbon for either type is specified as 0.06% max., then the chromium content should probably be further reduced to the 11.0 to 12.5% range.

The embrittlement reported by Messrs. Newell and Holmberg of the Type 405 field-welded strip lining in a hot oil separator after five years of service at about 735° F. could not be substantiated by carefully controlled bend tests on a sample removed from the vessel. Our investigation would indicate no preferential embrittlement of the Type 405 over the Type 410 reported as being ductile. The evidence of age hardening in both alloys is attributed in the Type 405 to a chromium content over 13% and in the Type 410 to a prior cold worked structure in the alloy strip which accelerated age hardening. Both alloys in this lining should be very thoroughly investigated when this is again possible, as the vessel is back in service at the present time.

Table IX — Alloys Exposed 9198 Hr. at 840 to 890° F. in Ammonia Converter

Chemical Analysis						Notch Bend After Exposure	Tensile Properties★				Rockwell Hardness
C	Mn	Si	Cr	Al	Mo		Yield	Ultimate	Elong.†	R.A.	
Type 410							39,200	69,900	30%	52%	B-73
0.04	0.45	0.38	12.40			OK; 160°	41,000	70,500	32	61	78
Type 405							48,000	73,100	30	42	77
0.07	0.41	0.22	12.65	0.10		OK; 140°‡	52,000	79,000	22	55	87
Type 405 Mo							47,700	72,000	32	67	79
0.07	0.32	0.25	12.08	0.27	0.57	OK; 50°‡	44,500	79,000	29	53	84
Type 410 Mo-Cb							51,500	73,500	34	58	72
0.08	0.50	0.40	12.73	Cb 0.47	0.53	Brittle; 6°	69,000	88,000	24	51	93
Type 405 (high Cr)							—	—	—	—	72
0.07	—	—	13.44	0.27		OK; 160°	—	—	—	—	86

★The results in the first line for each type are for original material; the second lines are after exposure. †Per cent elongation in ⅝-in. gage length (sheet samples). ‡Split longitudinally due to banding.

Correspondence

Shot-Peening of Springs

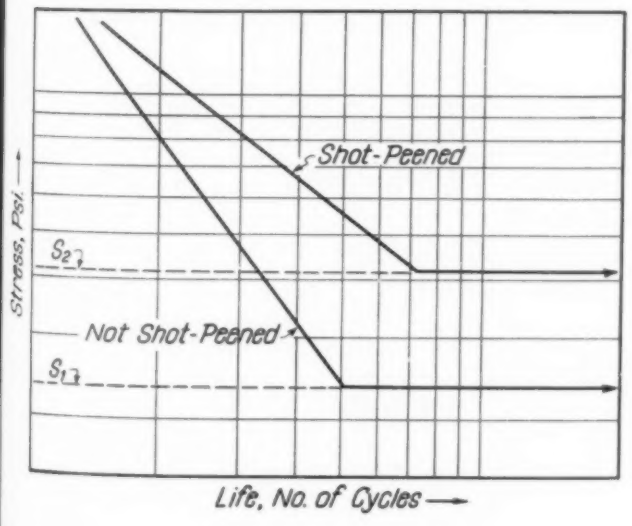
MISHAWAKA, IND.

To the Readers of METAL PROGRESS:

In his letter in the October 1946 issue of *Metal Progress,* Alberto Oreffice writes that reports of increases up to 1000% in the life of springs as a result of shot-peening are, in his opinion, too optimistic and he lists as evidence some test results of his own experience which show life increases ranging from 30 to 125%.

Because of the wide variety of factors affecting the results in a shot-peening test, it is quite possible to obtain fatigue life improvements as widely divergent as 30% and 1000%, even on identical parts. Two of these factors which have an important influence on the test results are *(a)* the maximum stress applied in the test and *(b)* the intensity of the peening blast.

As an example of the effect that stress-range can have on shot-peening, consider a typical S-N diagram as shown herewith. From this diagram it will be readily apparent that a part which is being subjected to a maximum stress somewhere in the



range between S_1 and S_2 will have a fairly definite, finite life in the unpeened state. If the part is peened and then tested to the same stress it will be seen that an indefinitely large increase in life can easily result. On parts which are tested at stresses above S_2 (which is apparently the range in which Mr. Oreffice did his testing) it will be seen that shot-peening will produce a limited life increase, frequently of an order of magnitude of less than 100%.

A good example of the effect of peening intensity on fatigue life is given in some tests on tank track pins run at the General Motors Research Laboratory. These tests showed that 1¼-in. diameter track pins, all tested under the same range of stress, developed an increase of life of about four times when the intensity of peening was increased from 0.004C1 to 0.015C1 (using the "C" test strip, 3 x ¾ x 0.0938 in.).

Aside from these two factors, the results of shot-peening are also affected by many other variables including design, material and previous treatment of the parts tested.

L. J. WIESCHHAUS
Market Research Engineer
American Foundry Equipment Co.

Mr. Oreffice Replies

I am glad that Mr. Wieschhaus has pointed out clearly the range of tests where comparisons of endurance life depend largely on how long you run the test.

Mr. Landecker, in last December's issue of *Metal Progress,* however, has misunderstood my remarks printed earlier. The wire torsion tests described in the October issue were not intended to be dynamic tests, but static tests. On the other hand the leaf springs tested in the peened and nonpeened state were loaded so the life would be about 100,000 cycles; under these circumstances, as stated, the fatigue life in our standardized test was doubled, or a little better.

The shot-peening operation in the tests reported was controlled by the Almen gage, using strip of S.A.E. 9260 steel, of Rockwell C-45 to 48 hardness, 3 in. x ¾ in. x 0.051 in. in dimension (the so-called "A" strip). Shot dimension is P19 by the S.A.E. standard (1946). After peening, the arc height (peening intensity) measured above a 1¼-in. chordal length as the concave, nonpeened side, is 0.0134 in. It may be that this intensity is not sufficient; future experience will decide this point.

ALBERTO OREFFICE
Chief Engineer, Steel Dept.
The Fiat Co., Turin, Italy

Low Versus High Pressure in Making Cemented Carbide Tools

LIEGE, BELGIUM

To the Readers of METAL PROGRESS:

It may be of general interest to compare the two methods for manufacturing hard carbide tool tips and inserts practiced for some years prior to the war at the Starachowice works in Poland. The methods contrast in the first cold pressing operation. One uses relatively low pressure, the other uses relatively high pressure. In either process the resulting compacts are presintered, shaped and then given the final sintering.

Pressing at low pressures follows the conventional practice. At Starachowice we used 22½-ton presses and demountable steel dies 6 in. long and 1 to 1½ in. wide. Heights of compacts were variable; specific pressure within the die was about 5600 psi. Plasticity of the powder was increased by a wetting liquid composed of gasoline, benzol and camphor. Even so the pressed compacts were very fragile. Preliminary sintering was done with compacts horizontal, in nickel alloy boats, pushed endwise through a tube furnace (wire wound) in a hydrogen atmosphere. Final sintering was in a carbon-tube, the tube itself being the resistor.

Pressing at high pressure was done dry (no wetting liquid) in 60-ton presses. The solid steel dies were 4½ in. long, 1⅜ in. wide, and the pressed height was 1⅛ to 1⅜ in. Unit pressure in the die amounted to about 12,800 psi. The pressed compacts were strong — even elastic — as they would bend appreciably before breaking. Preliminary sintering was done with the bars in a vertical position — standing on end. This was a major improvement, as no longitudinal temperature stresses were introduced when the bars passed slowly from the high temperature zone to the cooling zone. After presintering, 2 or 3 mm. of all surfaces was ground off — thus removing the material in which most of the internal stresses reside. Shaping must be done with rubber-bonded abrasive wheels.

Specific gravity of bars prior to sintering is:

Composition			Specific Gravity		
WC	TiC	Co	Low Pressed	High Pressed	Finished Tips
78.5	16.0	5.5	5.2	6.5	11.1
76.0	16.0	8.0	5.2	6.5	11.1
89.5	5.0	5.5	6.3	7.8	13.3
94.5	—	5.5	6.6	8.7	14.7

Beyond all these figures and suppositions that the method of high pressure pressing and subsequent fabrication should produce tips with the least shrinkage and the least internal strain — and therefore with less scrap in process and less failures in practice — is the record of production. In my experience the high pressure compacts were converted into small tips, weighing up to 10 g. Production losses in these small sized tips made by the low pressure method were 4% over a period of years. The production losses by the high pressure method were 1%.

ANTON NIEDZWIEDSKI
Former Manager, Carbide Dept.
Starachowice Steelworks

Ghost

BURBANK, CALIF.

To the Readers of METAL PROGRESS:

While observing the bond between copper brazing on vitallium, the formidable object shown in

the accompanying micrograph appeared within view. Jet propelled, perhaps, seeing that it has a plastic nose and overdeveloped tail boom or fuselage.

A. R. HUGHES
Laboratory No. 2, Triplett & Barton, Inc.

Facilities of the Wear Research Institute

STUTTGART, GERMANY

To the Readers of METAL PROGRESS:

It will be of interest to American engineers and metallurgists who have to do with difficult problems of wear — metal against metal, or of metal by abrasive mineral — to know that the Wear Research Institute of the former German Office for Technical

Sciences has been reconstituted by the U. S. Military Government's Research Control. This Institute was organized some 20 years ago and has in the meantime devoted its attention exclusively to the problems of wear, both from a scientific and practical standpoint. Its laboratories occupy one entire floor of an adequately serviced building, approximately 110x70 ft. in area. They are equipped with all the best-known wear testing machines (such as the Amsler, Brinell, Nieberding, Mohr and Federhaff, Sawin, Spindel) as well as many special devices designed for problems studied in the past. The laboratories also contain all necessary auxiliary equipment for physical chemistry, metallography, optics, and electrical measurements.

Possibly of most immediate availability is what is undoubtedly the most complete library in existence on the problems of wear. It includes nearly 5000 publications and manuscripts, thoroughly digested and cross-indexed.

It is to be hoped that this unique combination of equipment, experienced personnel and store of recorded information can be utilized by the peoples of all countries. At least that was the aim expressed by the responsible head of the U. S. Military Government when permission was granted to re-establish this laboratory. All personnel has been screened by the occupying authorities and passed after intensive examination.

This hoped-for cooperation may take the form of an examination of the literature and records of a problem in wear, an experimental program designed to solve a special difficulty, or the placement of American investigators in our laboratory in Stuttgart where they can use the excellent equipment already in existence. The present personnel in our laboratory is such that the language difficulty will not arise.

HANS WAHL; Dr-Ing.
Manager and Custodian
Wear Research Institute

Refractory Life in Side-Blown Converters

LONDON, ENGLAND

To the Readers of METAL PROGRESS:

A questionnaire was recently circulated to steel foundries in Britain by the British Iron and Steel Research Association, in order to obtain some general picture as to techniques and procedure, and returns were analyzed to determine a starting point for research on side-blown converters. Some 22 firms replied, and although conditions were found to vary widely, several points of interest emerged. A preference for monolithic linings was noted for small vessels, with an increasing tendency toward brick linings as the capacities increased — yet the number of heats blown during a run was found to be almost identical, irrespective of capacity.

Four plants charge sand into the converter with the iron, the amounts varying from two to eight shovelfuls at two works and from 40 to 80 lb. at the other two. This substantially improved lining life, especially around the tuyere level, probably due to the silica sand providing an acid oxide readily available for the iron oxide formed in the early stages of blowing, which would otherwise attack the acid lining near the surface of the metal. One plant used sand additions originally because the charge was a very low-silicon iron; the other plants later adopted the idea for iron with a normal silicon content. It is also possible that with longer intervals between heats, there is some fritting of the sand to the lining. The cost involved is, of course, very low, particularly if old core sand is used. The benefit of increased lining life applies particularly to plants blowing low-silicon irons; further controlled investigations are recommended before drawing definite conclusions for other circumstances.

One plant has studied the temperature distribution through a converter lining during several blows. Thermocouples were placed in the brick lining at various depths from the hot surface (½, 5, 10 and 17 in.) and a typical heat gradient was recorded as 2670, 1690, 1200, and 315° F. respectively, with the blown metal at 3100° F. Thus, points ½ in. into the lining from the molten metal may be 475° cooler than the bath. This, connected with the relatively short duration of the blow, probably accounts for the successful use of materials whose ultimate refractoriness may be appreciably lower than the temperature of the blown metal. Such thermal experiments suggest that when a converter is blowing successive charges, the average hot-face temperature is some 180° F. above that when one converter is blowing alternately with another. This figure relates to plant conditions involving the minimum of delay between successive heats.

T. BISHOP

Source of Polishing Scratches

MADISON, WIS.

To the Readers of METAL PROGRESS:

The writer, being old-fashioned, has continued to do most of his final polishing of metallographic specimens by hand despite the obvious advantages of electropolishing for certain types of work. Sufficient varieties of polishing cloths, abrasives and techniques are available so that specimens can be prepared by hand that are usually at least the equal

of those prepared by electropolishing. They can also be prepared more rapidly, unless electro equipment and fixtures are modern and adaptable.

Scratches remaining after the final polish are the bane of the metallographer who has pride in his work, and during a recent personal epidemic, an attempt was made to list all possible sources of the stray abrasive particles that wandered into the field of action. Here it is:

1. Dust particles in the air. Their concentration varies enormously with the location and, to some extent, with the weather. The writer worked several years in a laboratory that was down-wind from a power plant operating on powdered fuel with no dust collectors. Before one attempted final polishing it was usually necessary to wait for a shift in the wind, so the fly ash would be blown away. In mill laboratories the polishing wheels are frequently enclosed in glass-topped boxes and reached through rubber curtains.

2. Dust on the polishing wheel covers. There are two schools of thought—one believes the cover should be laid face down on the table when not on the wheel; the other, that it should repose face up. If housekeeping is immaculate and the polishing table is carefully sponged off first, then it is probably safe to lay the lid face down. This also protects the inside surface of the lid from dust particles settling on it from the air. (They will not settle on the wheel itself if it is running because of air currents over the surface of the wheel.) It is generally safer, however, to take a chance on the dust particles in the air rather than grit on the table, and place the lid face up when off the wheel.

3. Dirt from the hands. Time and again the writer has picked up the dusty levigated alumina bottle or wheel cover, laid a specimen on the dirty table, and then held the specimen on the wheel with the same hand and proceeded to wash the dust off his hand onto the wheel. To avoid this, the meticulous metallographer must virtually develop an operating-room or surgical technique, wherein the hand that holds the specimen is used for nothing else. Professorial absent-mindedness is not helpful.

4. Dirt in new polishing cloths, acquired during manufacture and handling. They will scratch a specimen every time unless boiled in distilled water for 20 to 30 min. and thoroughly washed.

5. Failure to cover the spouts of the polishing suspension bottles when not in use. Dust from the air settles on the spout and is transferred to the wheel with the first squirt of abrasive.

6. Improper levigation of polishing suspensions. To avoid caking of the abrasive while standing, or to get better suspension, sodium silicate or soap are sometimes added to the water. These agents also prevent rapid settling and hence defeat the purpose of levigation. If deemed necessary they should be added after levigation.

7. Soapstone from rubber stoppers or tubing used to siphon polishing suspensions from one bottle to another. This is a very troublesome source of tramp abrasive because it is virtually impossible to remove soapstone particles from the rubber. The only cure is to use stoppers or tubing that have never been coated with soapstone.

8. Carelessness in washing specimens free of abrasive from the previous wheel. Use a soft bristle brush, particularly when polishing specimens having rough surfaces.

Despite the elimination (as far as possible) of all sources of stray dirt particles as listed above, one is still occasionally confronted with several nice scratches suddenly appearing across the area of interest in the specimen. The cause of such scratches remains unknown to the writer, but one is inclined to blame them on *(a)* dandruff, *(b)* some peculiar form of attraction, aggregation or lumping together of the correctly-sized abrasive particles, or *(c)* perhaps more wisely to the mere perversity of fate. Nevertheless, once tramp abrasive gets on the cloth, the only thing to do is to remove it and boil it in distilled water, just as with a new cloth. The other alternative is to forget the whole thing and electropolish!

DAVID J. MACK
Assistant Professor, Administrative
College of Engineering
University of Wisconsin

C. Mentite Flees Pearl Ite

MINNEAPOLIS, MINN.

To the Readers of METAL PROGRESS:

A. P. Barone, formerly of this department, made an action shot of Mr. C. Mentite, seemingly fleeing from an entanglement with Miss Pearl Ite, appropriately enough in a field of "Ni-Resist". One suspects him of being two-faced, for he appears to be looking backward with a frown as well as forward with a smile!

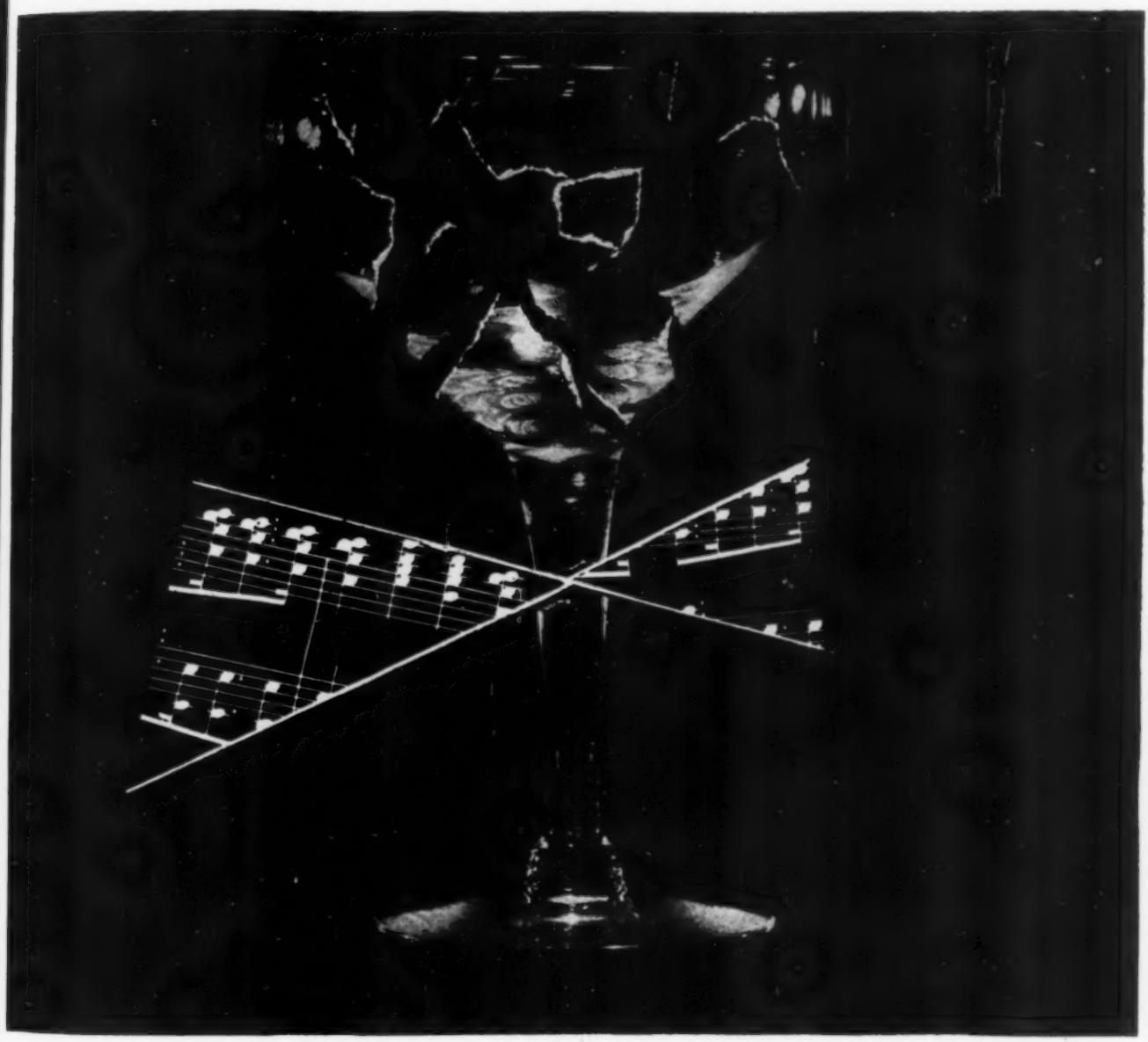
R. H. LUNDQUIST
Supervisor, Metallurgical Laboratory
Minneapolis-Moline Power Implement Co.

A FEW NOTES TO REMEMBER

It is possible to shatter a wine glass with a sustained musical note because the glass is too brittle to distribute the peak stresses that are set up by resonance.

For the same reason, failure can result in a brittle steel, with far more serious consequences than a mere broken glass.

One way to increase safety factor and to obtain many other advantages, is to specify temper-brittle-free molybdenum steels. These *modern* steels, which also provide good hardenability, good strength-weight ratio, and economy, are permitting many users to simplify — and save. Write for practical data.



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MOLY

Personals

Charles W. Adams ⊖, formerly with the engineering department of Waterloo Manufacturing Co., Ltd., is now engineer with the technical department, Arvida, Quebec, works of the Aluminum Co. of Canada, Ltd.

M. E. Harris ⊖ has recently organized his own firm to deal in mill, hardware, and electrical supplies, in Los Angeles, Calif.

William S. Craig ⊖, chairman of the Ontario Chapter ⊖, has recently been appointed general manager of Stamped & Enameled Ware, Ltd., Hespeler, Canada.

George I. Calvert ⊖ has been assigned by the Army Ordnance Department to the ordnance research and development division in Washington, D. C.

Don A. Lawless ⊖, former head of the technical service department, aluminum sales division of Reynolds Metals Co., is now technical adviser at the general sales office of Permanente Products Co., Oakland, Calif.

Roger J. Metzler ⊖, member of the board of directors of the New Jersey Chapter ⊖, formerly chief metallurgist of Breeze Corporations, Inc., is now development engineer with Handy and Harman, New York City.

E. W. Rainey ⊖, formerly wire mill superintendent, California Wire Cloth Corp., has accepted the position of chief metallurgist with the Northwestern Steel and Wire Co., Sterling, Ill.

Gilbert E. Klein ⊖, formerly a member of the research staff of Massachusetts Institute of Technology, is joining the engineering laboratories of the Burgess Battery Co., Freeport, Ill., as research engineer.

Clifford L. Nelson ⊖ has been promoted from the service department of Central Illinois Electric and Gas Co., Rockford, Ill., to the position of industrial gas sales representative of the company.

William A. Newcombe ⊖, formerly of Flint, Mich., is now associated with Aircraft Engineering Co. of Chula Vista, Calif.

Lawrence R. Foote ⊖, former industrial gas engineer for the Central Illinois Electric and Gas Co., has taken a position with the Bryant Heater Co. as industrial gas representative in the New York area.

Russell G. McMillen ⊖, formerly chief metallurgist for the Eastern Casting Corp. in New York City, is now vice-president in charge of operations in their new permanent mold division in Newburgh, N. Y.

Formerly supervisor of Eastern Optical Testing Laboratories, Inc., **E. Floyd Hassell** ⊖ is now experimental machinist in the electronic laboratory of Brookhaven National Laboratory, Associated Universities, Inc.

George Bennett ⊖, formerly supervisor of tool engineering, Fruehauf Trailer Co., Detroit, is now plant development engineer with M & M, Ltd., Newark, N. J.

C. A. Dewbery ⊖ is now designing and estimating engineer at Northern Machine Works, Ltd., Bathurst, New Brunswick, Canada. He was previously with the aircraft division, Canadian Car & Foundry Co., Ltd.

F. John McMulkin ⊖ has recently joined the staff of the Dominion Foundries & Steel, Ltd., Hamilton, Ont., as research engineer, leaving the position of senior research metallurgist, Ontario Research Foundation, Toronto, Ont.

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provides protection for both painted and unpainted aluminum comparable to that of anodically formed coatings but at a fraction of the cost in time, materials, labor, and equipment.

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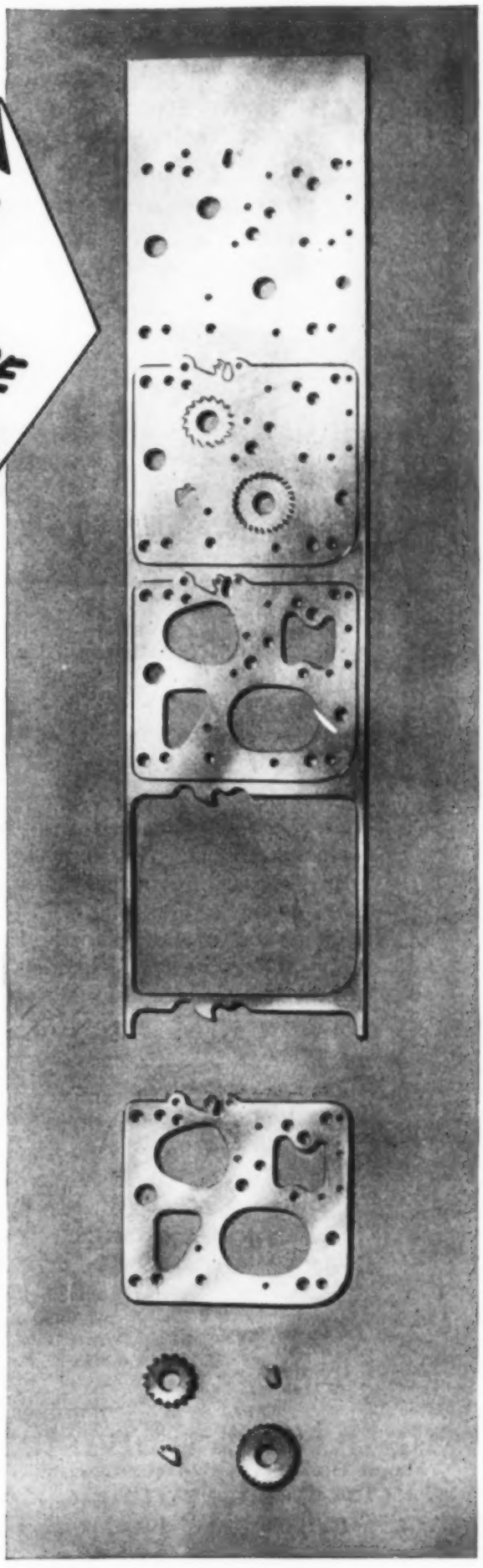
Rodine *

AMERICAN CHEMICAL PAINT CO.
AMBLER ACP PENNA.

CLEVER PLANNING REDUCES SCRAP— SPEEDS MANUFACTURE



THIS photograph shows progressive steps in the manufacture of a clock frame, and is an excellent example of careful planning to reduce the amount of scrap and lessen the number of operations. Note that in only a few strokes of the machine not only is a plate punched for the frame, but also a gear, a ratchet wheel, and two other small parts are produced. The work is done on a dieing machine, which operates to the very close limits that are essential in a clock. An additional item of economy is the fact that most of the other parts are made from exactly the same kind and gauge of metal, greatly simplifying purchasing, stockroom management, and production ordering.

Planning such as this is more important than ever today, when metal is scarce, and it is essential to conserve it, as well as lessen costs and speed production.

The metal used is Revere Leaded Brass, supplied to exceptionally close limits as to composition, gauge, temper, flatness, and straightness. Revere takes pride in its ability to meet these strict requirements, and will be glad to collaborate with any manufacturer in working out the application of its metals to modern, simple, accurate, metal-and-money-saving plans and processes.

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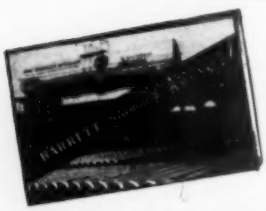

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Personals

After his release to inactive duty by the Navy, **Richard F. Baley** accepted the position of metallurgist with the Ferro Machine and Foundry Co., Cleveland, Ohio.

Fred W. Boynton has taken a position as technical adviser in the technical service department of the aluminum sales division, the Reynolds Metals Co., Louisville, Ky. He was formerly plant metallurgist in the aluminum extrusion plant of the Bohn Aluminum & Brass Corp., Adrian, Mich.

Howard B. Huntress, American Brake Shoe Co., Mahwah, N. J., has been transferred from the metallurgical department to the new chemical laboratory where he will engage in research on metal powders.

Victor H. Munnecke has been appointed purchasing agent of the Wiley Alloy Tube Co., Chicago.

Richard C. Barry, formerly of the Standard Oil Co. of California, is now continuing his graduate studies in the department of metallurgy at Stanford University.

Lloyd H. Davidson has been assigned to the position of manager of the product development department of the Avco Manufacturing Corp., Connersville, Ind.

Robert M. Gontz has returned to his former position of metallurgical engineer at Titan Metal Manufacturing Co., Bellefonte, Pa., following two years in the U. S. Navy.

The Navy Department has transferred **Arthur C. Gehringer** from the office of the inspector of naval materials at Cincinnati, Ohio, to assume charge of Army and Navy inspection at Alcoa's Lafayette, Ind., works.

Paul C. Cunnick is at present deputy commander of the 143rd Ordnance Base, Automotive Maintenance Battalion, in Germany, rebuilding engines and power trains.

John C. Annesley, formerly in charge of Aluminum Co. of Canada, Ltd., Montreal sales office, has been appointed manager of the Toronto sales office.

Resigning his position with Carboloy Co., Detroit, **L. J. Hull** has joined the jet propulsion laboratory of California Institute of Technology, Pasadena, Calif., as metallurgist.

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For precision control of heating from 300° to 2000° F., including *low temperature applications* such as tempering or drawing of steels, non-ferrous heat treating, etc., MK and VK model furnaces are equipped with a **Selective** Power Modifier to supplement the controlling pyrometer. This combination corrects the characteristic lag of chamber temperatures behind the pyrometer reading to as low as 300° F., and eliminates low temperature overshooting.

USE COOLEY FURNACES FOR:

- **Metallurgical Laboratory Heat Treating.**
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CHAMBER	8"W 6"H 14"L				10"W 6"H 18"L				8"W 6"H 14"L
MAX. TEMP.	1850° F.				1850° F.				2000° F.
AMPERES	14.8 at 230 v.				19.6 at 230 v.				20.2 at 230 v.
WATTS	3400				4500				4650
MODEL*	MH-3	VH-3	MK-3	VK-3	MH-4	VH-4	MK-4	VK-4	VK-5
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* M models complete with hinged door and hearth plate.
V models have counterweighted vertical lift door with adjustable opening.
K models include Selective Power Modifier for input control to correct temperature lag.

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Electronic operated Veri-Tron indicating and controlling pyrometer, with thermocouple and lead wire $143.00
Same in self-contained, enclosed panel including line switch and fuses, with steel stand—completely wired 240.00
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Export Manager, 44 Whitehall Street, New York, New York

Personals

Alloy Rods Co., York, Pa., announces the appointment of **Richard K. Lee** to the position of technical director of the company. Mr. Lee has been research engineer working on welding metallurgy and electrodes for the past six years.

E. E. Thum, editor of *Metal Progress*, **John Chipman**, professor of metallurgy, Massachusetts Institute of Technology, **H. J. French**, vice-president of the International Nickel Co., Inc., **O. T. Marzke**, supervisor, Naval Research Laboratory, and **Cyril S. Smith**, chief of the Institute of Metals at the University of Chicago, have been appointed to form a metallurgical advisory committee to the National Bureau of Standards.

Richard C. Pranik, past chairman of the Rhode Island Chapter, has been appointed vice-president in charge of engineering and manufacturing of the Seaboard Screw Corp., Providence, R. I.

Daniel J. Maykuth, Army veteran and former member of the faculty of Michigan College of Mining and Technology, has been appointed to the research staff of Battelle Memorial Institute, Columbus, Ohio.

The American Rolling Mill Co. announces the appointment of **T. F. Oldt** as director of research; he has been with the company for 19 years and has been assistant director of research since 1945.

William E. Walsh, formerly chief engineer, design division, Cowles & Co., Inc., has organized his own engineering company, Walsh, Inc., Chicago.

Zolly Carlton Van Schwartz, until recently chief machinery engineer with Peck Stow & Wilcox Co., has been put in charge of the standards department of General Machinery Corp., Hamilton, Ohio.

J. Lester Perry, previously assistant to the president of the United States Steel Corp. of Delaware, has been elected president of the Columbia Steel Co., West Coast subsidiary of United States Steel Corp.

Robert A. Miller, ex-Army officer and formerly metallurgist at Inland Steel Co., has been appointed to the research staff of Battelle Memorial Institute, Columbus, Ohio, where he will be associated with its division of industrial physics.

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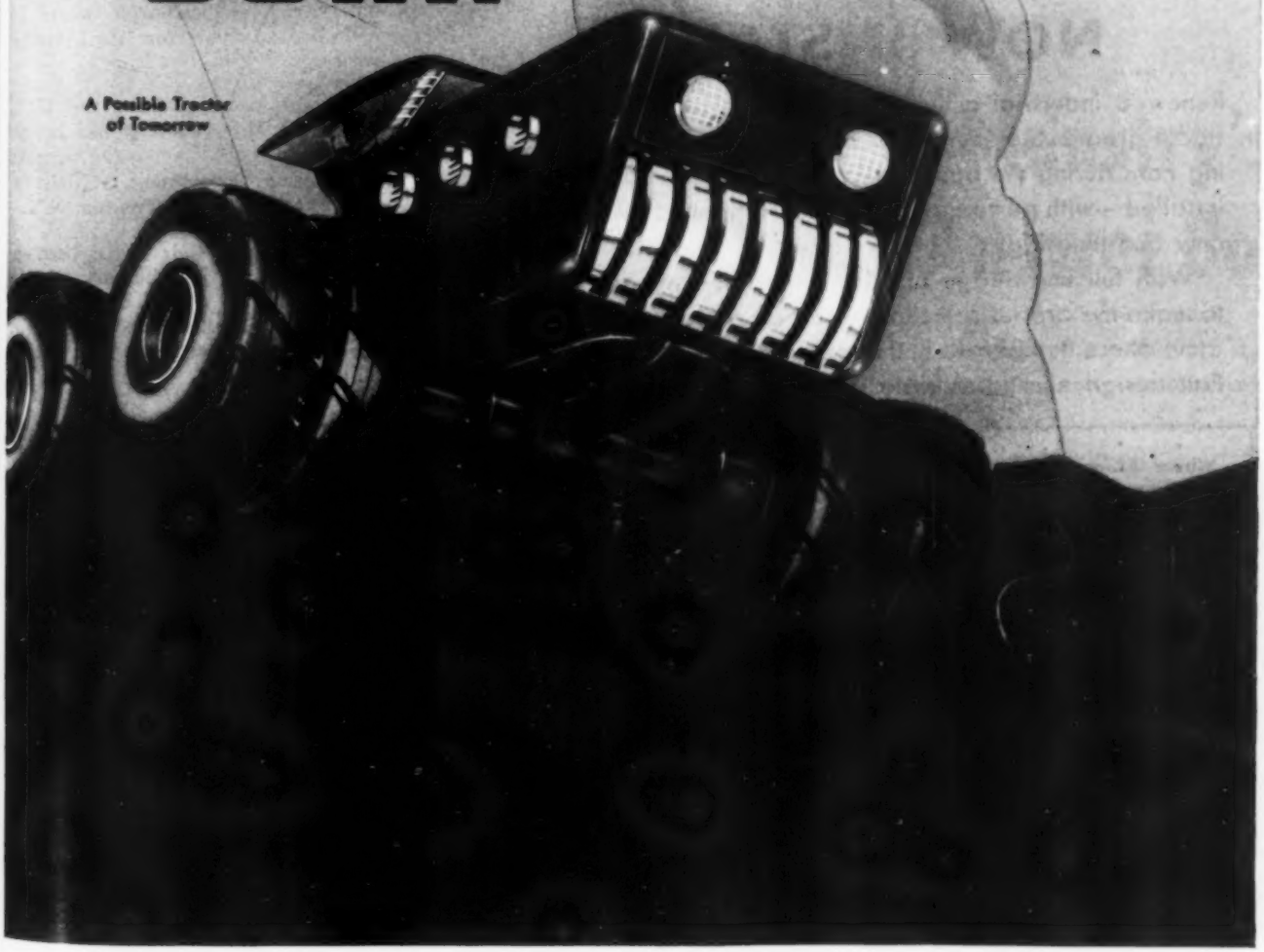
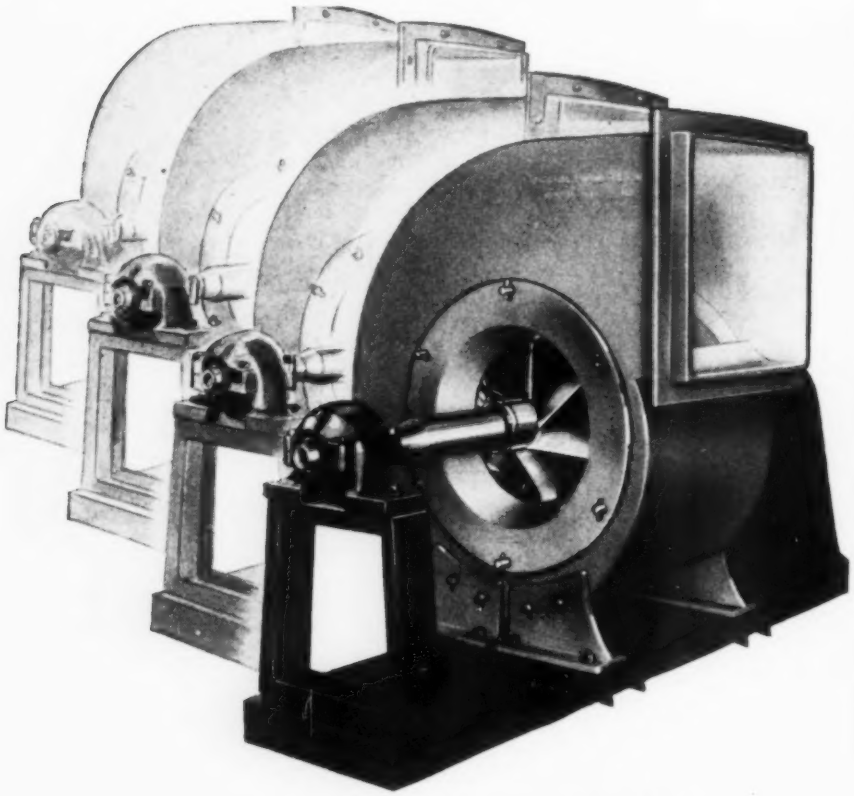


A Possible Tractor of Tomorrow



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Where Abrasion or Moisture are Factors

Where gases may contain abrasive dust—but temperatures are not excessive—abrasion-resistant alloys are available. Where resistance to corrosion is required, Michiana stainless steel castings may be employed. Thus the service indicates the alloy materials to be used.

MICHIANA Fans will help you improve output and uniformity of product. Their long life makes them economical . . . Our engineers are ready to make practical recommendations . . . MICHIANA PRODUCTS CORPORATION, Michigan City, Indiana.

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HIGH TEMPERATURE, RECIRCULATING FANS

Write for Bulletin 645

Personals

C. E. Vorobik is now project engineer in charge of product development at Kirsten Pipe Co., Seattle, Wash.

C. W. Schemm has joined Sverdrup & Parcel, consulting engineers of St. Louis, Mo., as chief electrical engineer with the assignment of organizing an electrical engineering section for the firm.

K. L. Walker, formerly welding engineer with Standard Oil Development Co., has been appointed assistant superintendent of the boiler shop, Foster-Wheeler Corp., Carteret, N. J.

Mehmet Baskal has returned to Turkey where he is working in Celik Fabrikasi, a steel plant in Kirikkale.

Vincent J. Walker, previously with Phillips Petroleum Co., is now with the Celanese Corp. of America, at the Chemcel Plant, Bishop, Texas, as mechanical designing engineer.

Lloyd's Register of Shipping have transferred **John M. Grove** from Baltimore to Pittsburgh where he will be surveyor for steel testing duties.

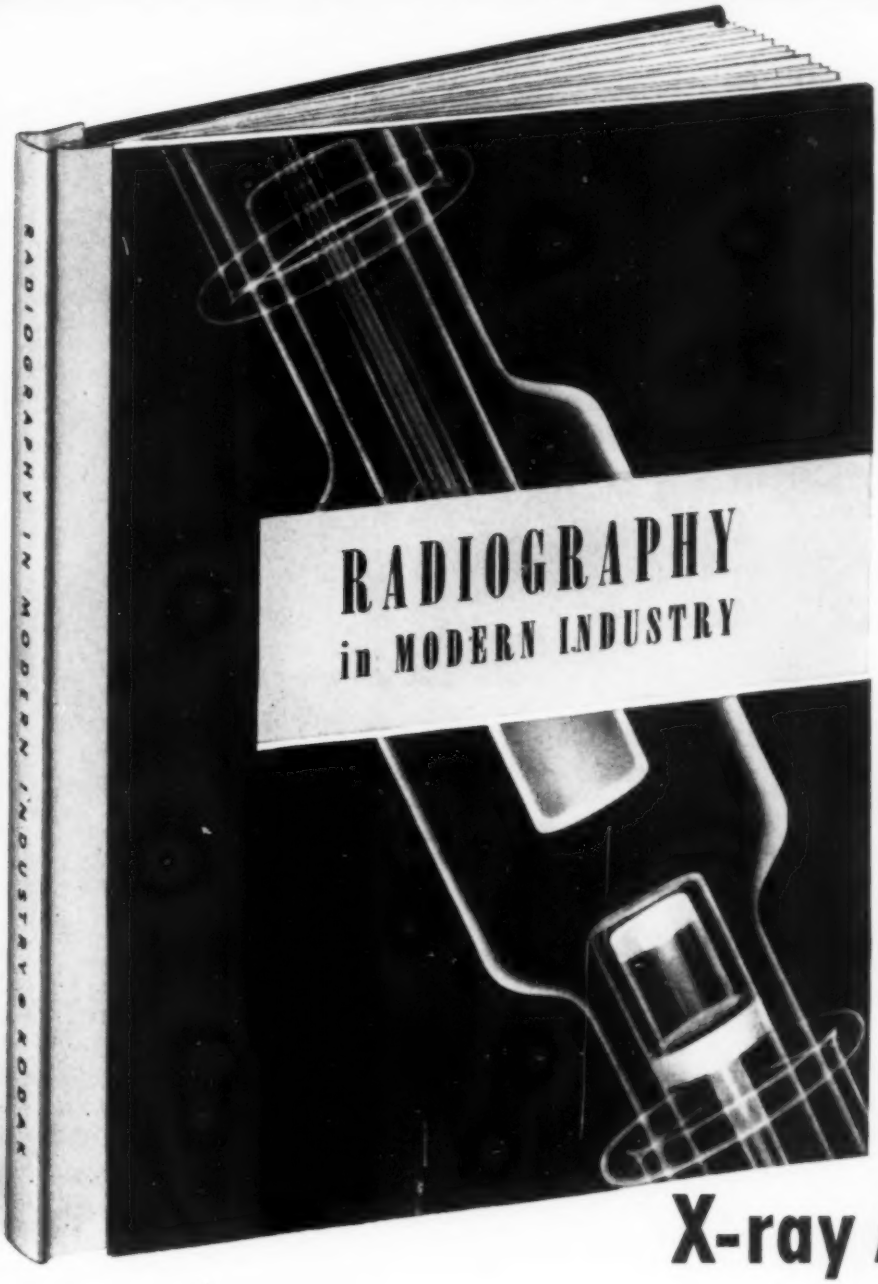
On his release from the U. S. Army, **H. M. Gruner** has become metallurgist of the development engineering department of John A. Roebling's Sons Co., Trenton, N. J.

Stuart E. Sinclair has been appointed chief metallurgist of the Greenfield Tap & Die Corp., Greenfield, Mass. He had been metallurgist for the Geometric Tool Co. division since 1936.

John A. Halgren, formerly works metallurgist at the Springfield, Ohio, works of the International Harvester Co., was promoted to the position of chief research metallurgist at the new manufacturing research division of International Harvester Co.

A. Frumkin, formerly with the Physical Metallurgy Research Laboratories of the Canadian Bureau of Mines, is now research metallurgist with the American Electro Metal Corp., Yonkers, N. Y.

David J. O'Neil, past chairman of the Hartford Chapter, has been appointed Pacific Coast manager of the Carpenter Steel Co. He has been with this company for 21 years and has been assistant branch manager in Hartford, Conn., since 1945.



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Personals

The Carpenter Steel Co., Reading, Pa., announces the following promotions: **O. V. Greene**, formerly manager of tool and alloy steel sales, has been appointed assistant general sales manager; **M. H. Goodman**, previously sales engineer in the New England territory, has been appointed assistant manager of stainless steel sales; and **E. Von Hamback**, research and development engineer, has been promoted from the Detroit area to headquarters in Reading.

The Colorado Fuel & Iron Corp. announces the following appointments: **A. F. Franz**, previously with Alan Wood Steel Co., as vice-president in charge of operations for all company plants; **Jay J. Martin**, formerly openhearth superintendent, as works manager of the Pueblo plant; **Rudolph Smith**, formerly assistant openhearth superintendent, as openhearth superintendent; **H. H. Christy** as superintendent of the power and water departments.

Walther Mathesius, president of Geneva Steel Co., Salt Lake City, Utah, has been elected a director of U. S. Steel Corp. of Delaware.

David C. Heckard is now instructor in metallurgy at Purdue University, Lafayette, Ind., and is working toward an advanced degree.

Nicholas Ribaudo has organized the Silver Plating Laboratories in Rochester, N. Y., for plating silver and gold exclusively.

R. P. Stemmler is now in charge of the tool steel division of the Allegheny Ludlum Steel Corp. in Los Angeles, Calif.

John D. Amoroso has become associated with the American Sigma Corp. of Buffalo, N. Y., as engineer and metallurgist to assist in sales, production and technical research.

Karl E. Ness, formerly metallurgist with the Gorham Tool Co., has been named president of the newly formed Induction Steel Castings Co., East Detroit, Mich.

Harold T. Harrison has accepted a position as research metallurgist with the National Cash Register Co., Dayton, Ohio.

David L. Kistler, formerly with International Minerals and Chemicals Corp., is now metallurgist in the remelt division, New Kensington works, Aluminum Co. of America.

How Riv

Riverside Nickel Silver is used in the fabrication of many essential parts of Ronson lighter products exposed to wear such as the shell and segments.

Special Note—A Ronson Lighter can't stay lit as shown on cake. "Press, it's lit—Release, it's out, the instant you lift your finger."

A good lighter is a most useful and efficient possession. But lighters are subject to severe abuse. Lighter manufacturers must take this fact into consideration and buy materials of the highest quality, to build lighters that will give uninterrupted service over a long period of years.

The makers of Ronson, one of the world's truly great lighters, use Riverside *Nickel Silver* to fabricate many essential parts (see above) exposed to wear. (Many of the Ronsons made more than twenty years ago are still giving unfailing service.) Riverside *Nickel Silver* is silvery white clear-through and, as the years pass by, its bright lustre does not wear off. It has an excellent surface for plating or polishing and readily takes a fine damaskeen-type finish.

Riverside *Nickel Silver* is tough, resistant to wear, fatigue and corrosion but easy to machine in any manner and weldable by all methods. It is extremely workable and can be formed, bent, drawn, stamped, punched, embossed or spun.

You may be able to improve your product with Riverside *Nickel Silver* or with Riverside's other alloys; *Phosphor Bronze* and *Beryllium Copper*. Our metallurgists are ready to help you. Write for information and catalogs.

INSIDE RIVERSIDE—*We not only say we are flexible in our thinking and operations; we have the alloys to prove it. Fifty years of supplying non-ferrous metals of a highly specialized nature, to almost every type industry you can name, has kept our minds young, our viewpoint fresh and our metallurgists active solving new problems and improving alloys. Tell us about your coming requirements, large or small. We think you'll like the way we tackle a job.*

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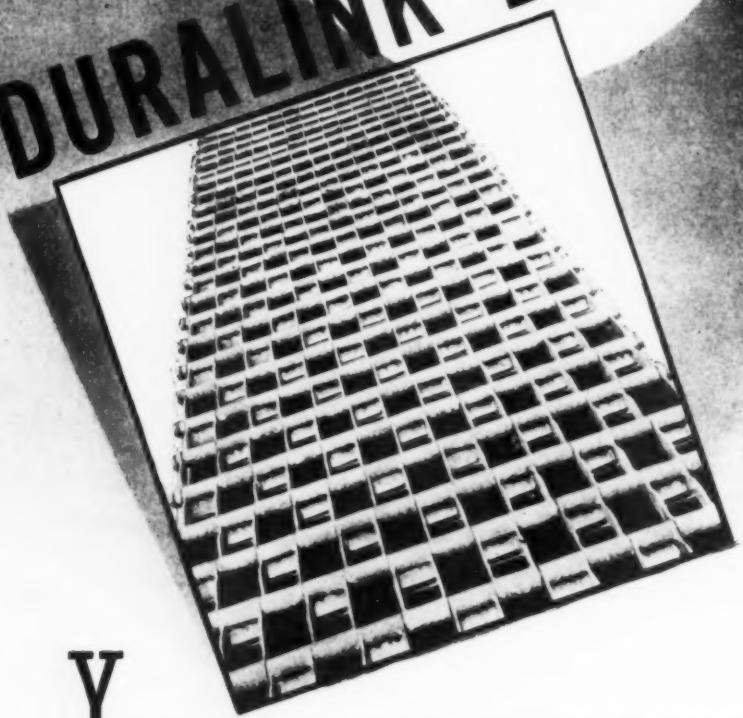

Yes, we designed it, cast and machined the parts and assembled the belt. It's destined for a coil-spring hardening furnace where it will have to absorb some rough treatment.

This belt goes to show what we can do in the way of casting a lot of small parts and, if desired, assembling them. We're just as well equipped to do this as we are to produce a single high alloy casting weighing 5 or 6 tons. Industry, with its widely varying demands, has found this flexibility of ours very useful when looking for chrome-iron and chrome-nickel castings.

7-DU-1

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Personals

Edward M. Schrock, who was quality control engineer at Aberdeen Proving Ground, now holds a similar position in the household refrigerator division of General Electric Co., and is located at Erie, Pa.

M. Victor Walberg, formerly with Columbia Steel Co., is now sales engineer and commodity manager of the stainless steel department of Pacific Metals Co.

H. C. Murrer announces that the Modern Tool Co., Cincinnati, Ohio, of which he was owner, has been incorporated and is now called the Murrer Tool Co., Inc.

Karl Klein has been appointed assistant works manager of the Bridgeport Brass Co., in charge of the east main plant.

D. K. Davis is now affiliated with Olin Industries, Inc., at Western Brass Mills, Winchester Repeating Arms Co., in New Haven, Conn., as metallurgical engineer in charge of the casting shop and of rolling mill processing.

J. Lynn Reynolds is now chief metallurgical engineer with Westinghouse Electric Corp.'s Sunnyvale works, Sunnyvale, Calif., since Westinghouse acquired Joshua Hendy Iron Works by whom he was formerly employed.

After 2 years in the U. S. Army, **Mitchell H. Weisman** has returned to North American Aviation, Inc., as a material and process engineer in the research engineering section.

On graduating from Missouri School of Mines and Metallurgy, **H. C. Dameron, Jr.**, accepted the position of metallurgist in the remelt department of the Aluminum Co. of America at their Lafayette, Ind., plant.

Ralph W. Fox has joined the staff of Armour Research Foundation, Chicago, as structural research engineer in the mechanics department.

C. S. McKinney is now chief engineer of the Youngstown Welding and Engineering Co., Youngstown, Ohio.

On his discharge from the U. S. Army, **Harold E. Christy** became associated with National Heat Treating Service Co., Columbus, Ohio, and he has recently been promoted to the position of plant superintendent.

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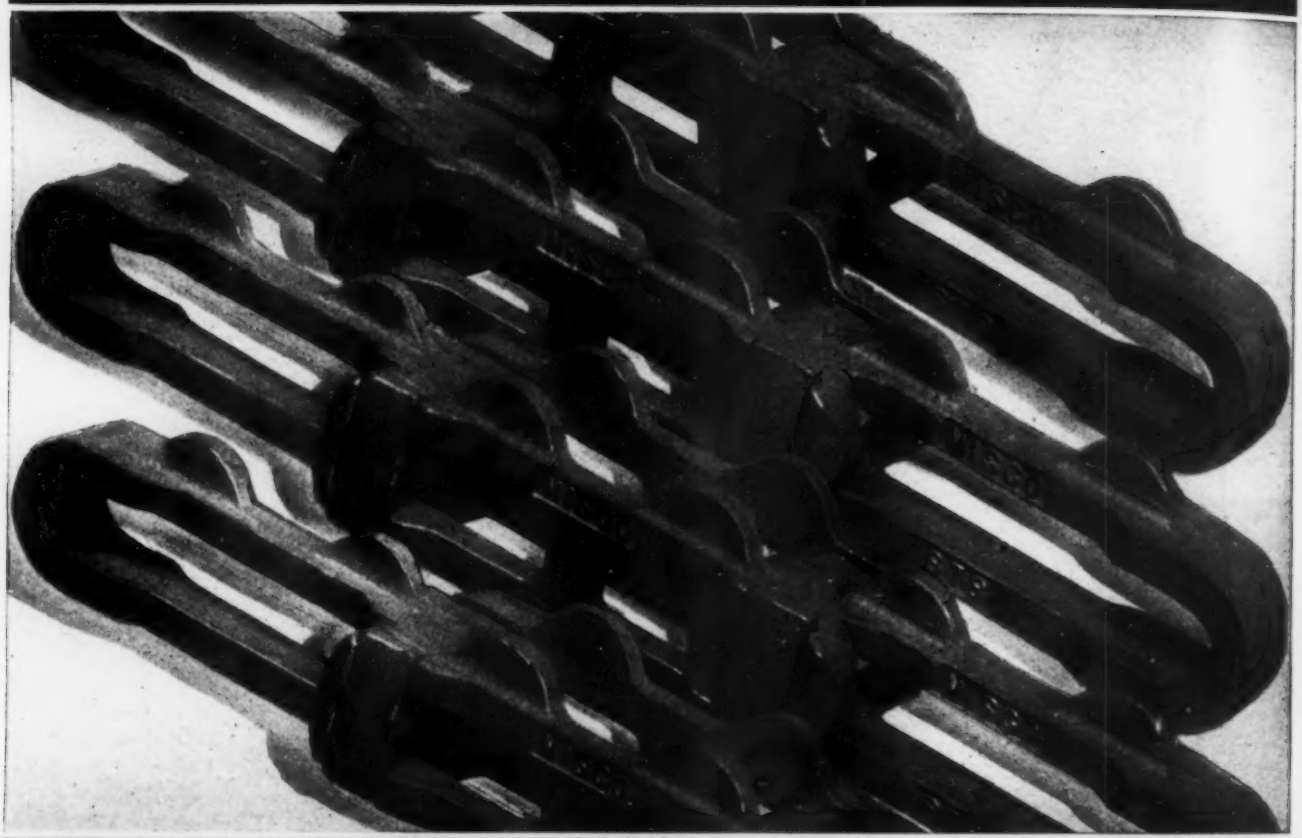

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